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SHF SATCOM INTERFERENCE STUDY

SYSTEM AVIONICS DIVISION (AA)
SYSTEM DEVELOPMENT BRANCH (AAD)

DECEMBER 1975

TECHNICAL REPORT AFAL-TR-75-251

FINAL REPORT FOR PERIOD MAY 1974 - JUNE 1975

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This technical report describes a cooperative study, measurement and analysis effort by the USAF and other Federal Agencies to experimentally quantify the potential interference between an airborne SHF SATCOM terminal and various terrestrial microwave and space systems operating in the 7.9 to 8.4 GHz frequency band. This investigation resulted because of concern voiced by the Office of Telecommunications Policy (OTP) based on a Spectrum Resource Assessment of the 7.25-8.40 GHz band conducted by the Department of Commerce,

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Office of Telecommunications. The Advanced Airborne Command Post plans to implement an airborne SHF SATCOM terminal aboard its E-4 aircraft to provide reliable command and control communications. Since the SHF frequency band (7.9-8.4 GHz) is allocated for terrestrial microwave and space system use, it was necessary to experimentally verify the interference potential of the airborne terminal and to identify spectrum sharing options. To assure this, a detailed analysis was performed to identify acceptable interference levels for a number of terrestrial microwave and space systems. Next, a series of ground and flight test measurements were made against representative terrestrial microwave terminals and the NASA Goldstone deep space tracking station. These results determined the mutual coupling levels between the airborne SHF SATCOM antennas and the terrestrial microwave and space system antennas. Received power levels and interference modes were investigated. The results of these tests were analyzed and conclusions drawn as to the probability of interference between the two systems under various conditions. Conclusions and recommendations were drawn from the analysis which would reduce the interference between the airborne SHF SATCOM terminal and terrestrial microwave systems to a tolerable level if a number of specific spectrum sharing options are implemented. Recommendations regarding a course of action to assure that these options are considered are presented.

FOREWORD

This Technical Report presents the findings of an investigation to experimentally evaluate the interference potential of an airborne SHF SATCOM terminal on terrestrial microwave and space systems that operate in a common frequency band. This effort resulted from concerns voiced by the Office of Telecommunications Policy (OTP) as a result of a Spectrum Resource Assessment of the 7.25-8.40 GHz frequency band conducted by the Department of Commerce, Office of Telecommunications. Because of the broad implications of the potential interactions, the USAF, as developer of the airborne SATCOM terminal, was identified by DOD to lead the investigation. The USAF in turn delegated this responsibility to the Air Force Avionics Laboratory (AFAL). AFAL called upon the expertise of the Department of Commerce, Office of Telecommunications (OT) and the Department of Defense, Electromagnetic Compatibility Analysis Center (ECAC) for direct support in performing the necessary study. In the conduct of the study, a large number of other agencies and individuals were called upon to assist in the various phases of the study. The authors wish to thank the following organizations without whose tremendous support the effort could not have been accomplished:

Office of Telecommunications Policy (OTP)
Energy Research and Development Administration (ERDA/AEC)
Department of the Interior (DOI)
Department of Commerce (DOC)
National Aeronautics and Space Administration (NASA)
NASA/Jet Propulsion Laboratory (JPL)
Defense Communication Agency (DCA)
Federal Aviation Administration (FAA)
Tennessee Valley Authority (TVA)
Bonneville Power Administration (BPA)
USAF/Frequency Management
USAF/E-4 System Program Office
Electronic System Division
Strategic Air Command (SAC)
Air Force Communication Service (AFCS)

This effort was accomplished during the period May 1974 through June 1975 under Project 1227, "Advanced Microwave Communications," task 12272205, "SATCOM Testing."

The project leader was Allen L. Johnson. Testing was under the direction of Roger L. Swanson (AFAL), Robert Mayher (OT), Richard Parlow (OT), Michael J. Kelly (ECAC/IITRI) and Paul Groot (ECAC/IITRI). Special thanks is extended to Major Robert L. Wasson who was in charge of AFAL's test effort from the project inception until his transfer in April 1975.

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SECTION I

GENERAL

INTRODUCTION

The Department of Defense (DOD) plans to implement a Super High Frequency (SHF) satellite communication (SATCOM) capability aboard the E-4 (Advanced Airborne Command Post) in order to provide reliable, jam-resistant communications for the command and control purposes. The SHF SATCOM system is designed to operate over the Defense Satellite Communications System (DSCS) which operates in the 7.25 to 8.4 GHz frequency band. In the DSCS Phase II satellites a portion of this frequency band from 7.25 to 7.30 GHz (downlink) and from 7.975 to 8.025 GHz (uplink) has been allocated exclusively for satellite use. The remainder of the DSCS II frequency band has been allocated as a shared band for ground terrestrial microwave use and other space systems. The users of this shared portion of the band are various government agencies which operate point-to-point microwave links plus other space systems.

Use of the exclusive satellite band by SATCOM terminals does not represent a significant interference threat to ground terrestrial microwave. However, SATCOM terminals in the shared portion of the DSCS II band represent a potential threat to the point-to-point terrestrial microwave users and other space systems. Most ground based SATCOM terminals are specifically located to avoid interference with other terrestrial microwave users. However, due to its mobility, the incorporation of a SHF SATCOM terminal in an airborne command post represents a potential interference to terrestrial microwave users operating in the shared frequency band under the situation

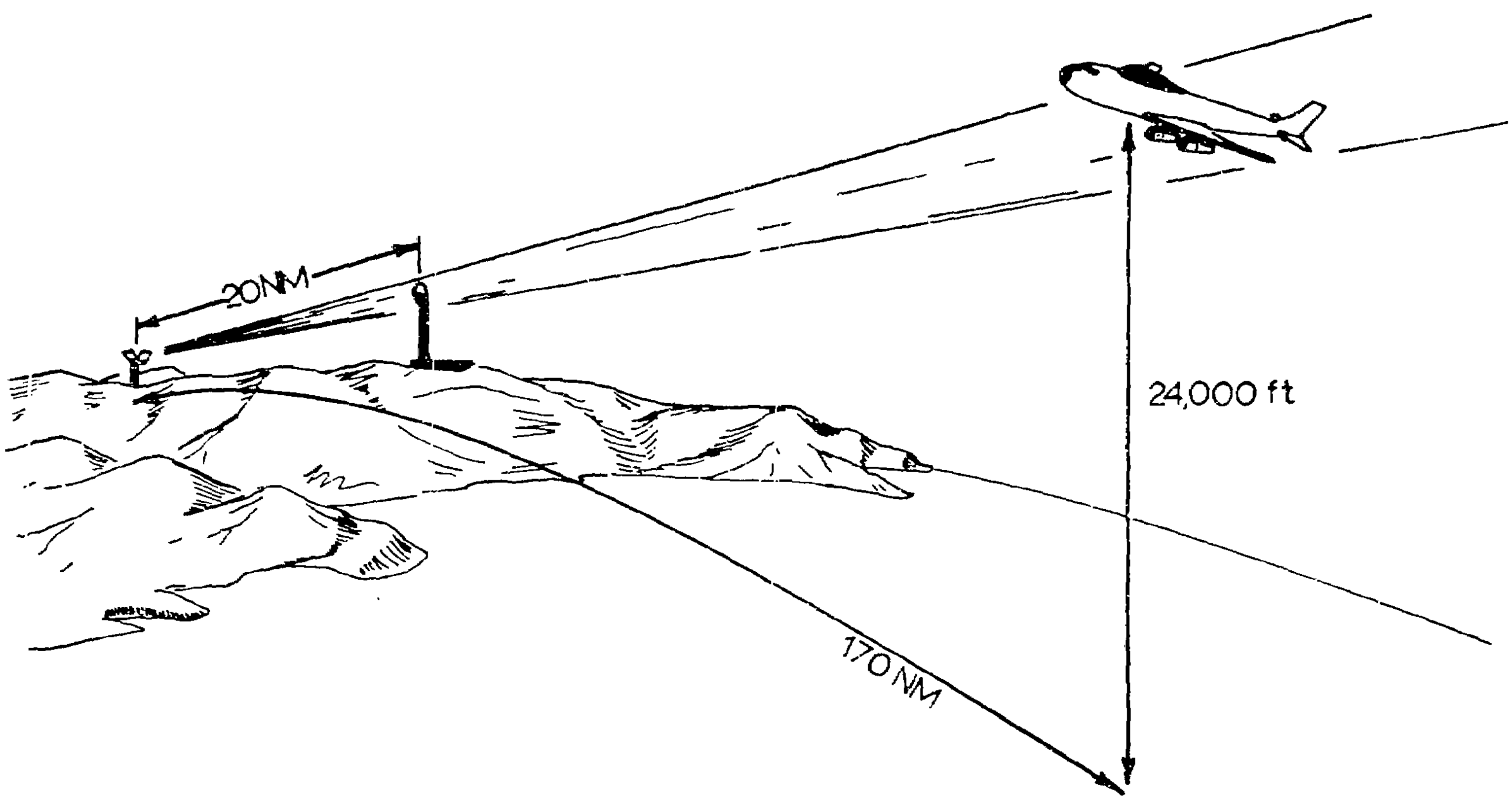


FIGURE 1 AIRBORNE SHF SATCOM INTERFERENCE GEOMETRY

shown in Figure 1. This figure depicts potential interference coupling between the sidelobes of the airborne SHF SATCOM terminal and the main beam of a terrestrial microwave receiver.

The airborne SHF SATCOM terminal developed for use on the E-4 (AN/ASC-18) can transmit at 1 watt to 10 kilowatts continuous power and utilizes a 32 dB directive antenna to communicate via the satellite.

In view of the potential interference threat which this airborne SHF SATCOM terminal represents when it flies near a terrestrial microwave user the Office of Telecommunications Policy (OTP) requested that the Air Force perform a detailed investigation to determine the seriousness of the interference threat prior to implementation of the operational SHF SATCOM system.

OBJECTIVE

The U.S. Air Force directed that the Air Force Systems Command (AFSC), who is responsible for both the AN/ASC-18 development and the E-4 program, perform the detailed study necessary to answer the interference question. AFSC designated the Air Force Avionics Laboratory (AFAL) as the Office of Primary Responsibility for conducting the interference investigation. AFAL hosted an initial meeting in May 1974 to define the objective of the test and the approach. The meeting was attended by those government agencies which operated terrestrial microwave links in the SHF shared satellite band and by organizations which intended to participate in the interference study. At this meeting it was decided that the objective of the SHF SATCOM Interference Study would be to "Determine the interference level generated in the terrestrial microwave terminals and space systems in the band by the Airborne

SHF SATCOM Terminal, to evaluate the effect of this interference on the performance of the terrestrial microwave system and identify alternate solutions."

APPROACH

In order to accomplish the objectives the following approach was selected:

A. Identification of terrestrial microwave users. The objective of this effort was to identify those agencies with systems operating in the 7.25 to 8.4 GHz band. This involved not only current users, but agencies which might be operating on that band in the future. The Office of Telecommunications Policy (OTP) accepted the chairmanship of this task. They accomplished this task by reviewing the computer listings for frequency assignments within the desired frequency band. They also polled agencies for potential future users who expected to operate in this band.

B. Terrestrial microwave system characteristics. The objective of this task was to identify the characteristics of the terrestrial microwave systems and other space systems operating within the selected frequency band. The Electromagnetic Compatibility Analysis Center (ECAC) accepted the chairmanship of this task. Their approach was to use the computer listings of the various band users to identify basic equipment types. Further discussions with each individual user to verify, clarify and add to the computer information was necessary in order to obtain the technical characteristics of the terrestrial microwave systems of interest. One of the characteristics to be determined was the expected fading outage. Since the total elimination of interference may not be possible there is a need to establish an acceptable level of interference. In general, if the interference occurs for a small percentage of the

normal fading outage time it would appear to be tolerable. The characteristics of the users' terminals are included in this report.

C. Establish signal-to-interference ratios. The objective of this task was to establish signal-to-interference levels which would provide criteria for protection of terrestrial microwave system operation. The Office of Telecommunication (OT) accepted chairmanship of this task.

Their approach to this task was to develop signal-to-interference (S/I) ratios which could be applied by each of the microwave users. They then assisted the users in evaluating their systems and in developing the necessary S/I ratios and associated maximum probability of occurrence values. These ratios provided the basis for the test analysis criteria and are contained in Reference 1.

D. Define expected SHF SATCOM operation on E-4. The objective of this task was to define the expected operational use of the airborne SHF SATCOM aboard the E-4. This would include the expected frequency, power and data rate to be used in addition to expected time and geographical location of airborne operations. The E-4 SPO at ESD accepted the chairmanship of this task.

Their approach to this task was to quiz the potential E-4 users (SAC and NEACP) to determine their expected operational scenario. They tried to determine who the command post would be operating with, at what data rates, what geographic locations, what satellite modes, what power, and during what times. The results of this effort are in SECTION IV - OPERATIONAL CONSIDERATIONS.

E. Interference Probability Analysis. The objective of this task was to determine the likelihood of interference being generated in the terrestrial microwave by the Airborne SHF SATCOM System. ECAC accepted the chairmanship of this task.

Their approach was to conduct a general study of the airborne SHF SATCOM terminal's impact on point-to-point microwave and other systems which share the common operating band. Guidelines were developed that aided in the identification of spectrum sharing options. Factors such as desired signal levels, fade margins, typical system characteristics, expected interference signal levels and aircraft overflights were considered. Their analysis is contained in References 2 and 3.

F. Data Collection. The objective of this task was to develop procedures for ground and airborne tests to collect the necessary test data. This included the task of providing the necessary monitoring and interfering equipment for the ground and airborne test. Final effort in this task was to actually perform the ground and airborne flight test. Air Force Avionics Laboratory (AFAL) accepted the chairmanship of this task.

The approach was to first examine the interference criteria and determine what testing needed to be done. Next the test equipment required was defined and collected. A ground test was performed at each site to verify the system parameters and establish a baseline for the flight test. The plan for the flight test was established and actual data collection accomplished by flying the interfering system in the vicinity of the terrestrial microwave link. The test plans and test reports were published in References 4 through 12.

G. <u>Analysis and Evaluation</u>. The objective of this task was to evaluate the data obtained from the previous six tasks and formulate recommended operational and management procedures for compatible operation of the airborne SHF SATCOM system and the terrestrial microwave systems. AFAL was chairman of this group.

The approach was to review all the data collected under the previous six tasks and provide a detailed analysis of the interference problem. This final report is the result of this evaluation. In order to cover extensions of these techniques to the more general interference problem, a summary report has been prepared.[13] That report considers the changes in bandwidths, powers, signal-to-noise or modulation techniques to be taken into account when applying these evaluation techniques to other systems.

It was agreed that the potential interference problem was a world-wide problem. However, it was decided to limit the study to the CONUS (48 contiguous states plus the District of Columbia). Once those problems were solved the effort could be expanded as required.

An initial look at the problem indicated that it would not be possible to perform an actual test against all microwave sites. It was decided to try to group the types of sites and pick representative sites for the actual test. As a result of the grouping six test sites were selected as typical. These were:

a. TVA's McEwen, Tennessee 600 Channel FM Voice Link

b. AEC's Nevada Test Site Close Circuit TV Link

c. AEC's Nevada Test Site Digital Link (NADS)

d. FAA's Jacksonville, Florida RML-4 Radar Remoting Link

e. FAA's Jacksonville, Florida RML-6 Radar Remoting Link

f. JPL's Goldstone, California 210' Space Track System

In selecting an approach for the study it was agreed to attempt to set up and validate an analysis procedure so that as future terrestrial microwave sites are added the interference problem can be satisfied by analysis. Testing against each new site is obviously not practical.

SECTION II

CONCLUSIONS

GENERAL

At the completion of the data collection and analysis the following conclusions were drawn relative to the potential interference between the airborne SHF SATCOM, the terrestrial microwave and other space systems. A more complete discussion of these conclusions is contained in the writeups on each of the individual tests in the later sections of this report.

ASSUMPTIONS

The conclusions are based on the following set of assumptions:

1. The analysis was based on the SHF band utilization contained in the IRAC file as of May 1974 updated by information on FAA, TVA, BPA, ERDA and JPL links late in 1975. Future changes to the SHF population will have to be considered to evaluate their susceptibility using the calculation techniques presented in this report.

2. The E-4 aircraft will be equipped with the airborne SHF SATCOM system (ASC-18) in the late 1970s. A total of six aircraft are planned for the E-4 fleet. There would seldom be an occasion for more than two of the six E-4s to be airborne at any one time.

3. The airborne SHF SATCOM system will be operated at the lowest power which will provide the required communication capacity (expected to be 100 to 1000 watts).

4. The planned E-4 SHF frequency utilization envisions two fifty megahertz bands centered at 8.150 and 8.240 GHz. The modulation is a direct sequence pseudo random noise with phase shift keying. All terminals

will use the same center frequencies and multiple access will be accomplished by code division.

5. While any interference with terrestrial microwave or other space systems is undesirable it is assumed that statistically derived levels of interference that produce a finite increase in outage over that caused by nature alone could be defined and recommended to the effected agencies.

6. The increase in outage time identified in the probability interference analysis was based on the assumption that the aircraft would be present within a specified set of signal-to-interference contours a given number of minutes per day. For any specific flight scenario, the actual flight time within these regions could be less and hence reduce the predicted increase in outage time. During this investigation, insufficient flight scenario data was available to allow the evaluation of flight time constraints in any given area, hence maximum limits have been identified.

7. The main beam of the airborne SHF SATCOM antenna will not be pointed lower than +10° elevation. The only coupling to the terrestrial microwave or other space systems will be through the sidelobes of the airborne antenna.

8. Initial calculations were done assuming an unfaded microwave link. Following that analysis the fading probabilities were evaluated to see what effect the airborne SHF SATCOM system would have on a microwave link during fading. For space systems in or planned for the band typical receiver noise temperatures and/or expected signals were considered.

100 WATT OPERATION

Cochannel operation of the airborne SHF SATCOM system at a reduced power of 100 watts reduces the interference to what is judged to be a tolerable level for all systems as long as the main beam of the JPL, ERSOS

and ERDA/NADS systems are avoided. The JPL and ERSOS systems have a main beam which is very narrow, 200 to 1000 feet diameter at expected flight altitudes (24,000 to 35,000 ft msl). The probability of main beam interception is very small, i.e., ≈ one in a million. For the ERDA/NADS protection can be provided by avoiding the main beam within 80 nm of the receiver or by tuning to a center frequency at least 45 MHz from the NADS. Use of the planned frequencies (8.150 and 8.240 GHz) would provide the required frequency separation for the JPL, ERSOS and ERDA/NADS systems.

1 kW OPERATION

Cochannel operation of the airborne SHF SATCOM system at a power of 1 kW increases the probability of outage to the FAA and one BPA link near Seattle due to interference only slightly from that presently experienced due to natural causes. For example, if the expected outage were presently 1×10^{-3} it might be increased to 1.5×10^{-3}. This probability assumes a limited number of flights through certain high probability areas, such as three hundred flights per year through certain main beams. Interference would not occur unless the FAA or BPA link were in a faded condition. It would still be necessary to avoid main beam interception of the JPL (Goldstone), ERSOS (Sioux Falls) and NADS (Nevada Test Site) systems. Center frequency separations of 50 MHz for JPL, 40 MHz for ERSOS and 48 MHz for NADS would reduce the probability of interference to what is judged to be a tolerable value. Use of the planned frequencies (8.150 and 8.240 GHz) would provide the required frequency separation for JPL, ERSOS and ERDA/NADS systems.

10 kW OPERATION

Operation of the airborne SHF SATCOM terminal at its full 10 kW power output using PN modulation could cause interference to FAA (continental),

BFA (one link near Seattle), ERDA/NADS (Nevada Test Site), JPL (Goldstone) and ERSOS (Sioux Falls) systems if the aircraft were to fly through the main beam of the microwave system while operating on the same channel. Other systems such as TVA, BPA (other than one link near Seattle) and ERDA-CCTV have sufficient link margin that there is only a very small probability that they would be interfered with. For example, the TVA outage probability might increase from $.4 \times 10^{-5}$ to $.6 \times 10^{-5}$. Outage would only occur if the TVA link were experiencing fading. If center frequency offsets of approximately 40 to 50 MHz (66 MHz for JPL) are provided between the airborne SHF SATCOM terminal and the affected system or if main beam interception is avoided, there is only a very small probability that interference would be encountered. Use of the planned frequencies (8.150 and 8.240 GHz) would provide the required frequency separations for the JPL, ERSOS and ERDA/NADS systems.

GROUND OPERATIONS

The airborne SHF SATCOM system will be operated on the ground while the E-4 is on alert. Calculations were performed to evaluate the potential interference to terrestrial microwave or other space systems located near the airport. The general conclusion was that there is a potential interference problem to microwave systems operating on nearby frequencies. It appears that each site where ground operation is planned will have to be analyzed on a case-by-case basis to assure power levels and operating frequencies are selected which will preclude interference to the local terrestrial microwave users.

EXCLUSIVE BAND OPERATION

Operation of the airborne SHF SATCOM system aboard the E-4 will utilize a DSCS-II satellite up until approximately 1980. During this time period the prime frequencies for operation (8.150 to 8.240 GHz) of the airborne SHF SATCOM system will be in the frequencies shared with terrestrial microwave and other space system users. Therefore, interference problems between the airborne SHF SATCOM system and the other users must be addressed. However, the planned development of a DSCS-III satellite includes the ability to shift the narrow beam operation from the shared portion of the band to the exclusive frequency band. The DSCS-III satellite is planned for operation in approximately 1980. At that time if the prime mode of operation of the airborne SHF SATCOM system on the E-4 shifts from the shared band to the exclusive satellite band, possible interference generated by the joint use of the shared portion of the satellite band should no longer be a problem. Operation at that time in the exclusive portion of the satellite band should preclude the possibility of serious interference problems between the airborne SHF SATCOM system, terrestrial microwave systems and other space systems. However, if the prime mode of operation is not shifted to the exclusive band serious restrictions on geographic location and/or frequency assignments of future systems will exist.

RECOMMENDATIONS

The following recommendations are offered:

1. As a long term solution to the interference problem, operation of the airborne SHF SATCOM system should be moved to the exclusive satellite band. This should be implemented in the DSCS-III satellite planned for the 1980 period. During the interim period operation of the airborne SHF

SATCOM system in the shared band should be maintained at the lowest power which satisfies the communication requirements.

2. Main beam interception of the other users should be avoided where practical.

3. Procedures should be established to assure that operation of the airborne SHF SATCOM system be accomplished without causing intolerable amounts of interference to other users.

4. Procedures should be established to assure that changes in the frequency assignment or user population will be evaluated to assure continued compatibility.

5. Potential interference problems should be coordinated with the agencies involved.

SECTION III

ANALYSIS APPROACH

GENERAL

The basic concept of the analysis effort was to make a series of measurements and calculations which could be applied to the general problem of interference between an airborne SHF SATCOM system, terrestrial microwave systems and other space systems. This required a series of predictions, calculations, ground (closed-system) measurements, and airborne (open-system) tests. Obviously, it is not possible to test all links nor to test under all possible conditions. Therefore, the plan was to test a representative sample of the types of links in use under realistic conditions.

In order to analyze the interference between the airborne and other systems sharing the band it is necessary to define the system parameters which may interact. These parameters include:

(1) modulation characteristics

(2) system frequencies and bandwidths

(3) type of information being transmitted

(4) link characteristics, including geometric considerations

(5) operational periods and data perishability

(6) design options

ANALYSIS PROCESS

The analysis process to be used in this report includes the following steps:

(1) Development of basic system equations.

(2) Application of predicted and measured link parameters.

(3) Calculation of predicted interference levels.

(4) Comparison of predicted and measured interference levels.

(5) Application of probability theory to determine probabilistic aspects of link outage times.

EQUATIONS

The equations contained in this section are used in the report to analyze predicted interference levels.

The interference processing gain (a similar expression could be given for gaussian noise) is generally defined[14] as:

$$PG' = \frac{(S/I)'_{OUT}}{(S/I)'_{IN}} \tag{3-1}$$

where

$(S/I)'_{OUT}$ = output signal-to-interference (or noise) in units

$(S/I)'_{IN}$ = input signal-to-interference (or noise) in units

For the case in which it is desired to express the processing gain (PG') in dB we have that:

$$PG = 10 \log PG' = (S/I)_{OUT} - (S/I)_{IN} \tag{3-2}$$

where

$(S/I)_{OUT}$ = output signal-to-interference (or noise) in dB

$(S/I)_{IN}$ = input signal-to-interference (or noise) in dB

For a multiple channel FM, the gaussian noise PG' for the highest channel and a high input (S/N) ratio is given by:[15]

$$PG'_N = \frac{(S/N)'_{OUT}}{(S/N)'_{IN}} = \left(\frac{F_{CH}}{f_m}\right)^2 \frac{B_{IF}}{b} \;.\; P \;.\; W \qquad (3\text{-}3)$$

where

B_{IF} = IF bandwidth

b = bandwidth of the telephone channel (3.1 kHz)

F_{CH} = the rms test tone deviation per channel (Hz)

f_m = mid-frequency of the highest baseband channel (Hz)

P = pre-emphasis improvement factor

W = psophometric weighing factor

A typical value for P is 4 dB and W is 2.5 dB. These values were applied where appropriate.

The PG' for the on-tune multichannel case and an unmodulated CW interfering signal is given by:[16]

$$PG'_{CW} = \sqrt{2\pi}\ \frac{F_{CH}^2 f_s}{b f_m^2}\ \exp(f_m^2/2f_s^2) \qquad (3\text{-}4)$$

where

f_s = $[\Delta f_b^2 + \Delta f_u^2]^{1/2}$ = total rms deviation

Δf_b = total rms deviation of desired signal

Δf_u = total rms deviation of undesired signal

The input desired signal can be conveniently calculated from the following expressions:

$$S_{IN}\ (\text{dBm}) = N_{IN}\ (\text{dBm}) + (S/N)_{IN}\ (\text{dB}) \qquad (3\text{-}5A)$$

$$= N_{IN} + (S/N)_{OUT} - PG \qquad (3\text{-}5B)$$

$$= -174\ \text{dBm} + NF + 10 \log B + (S/I)_{IN} \qquad (3\text{-}5C)$$

where

N_{IN} = input noise (typically expressed in dBm)

NF = noise figure in dB

B = bandwidth in Hz

The desired signal (S_{IN}) at the receiver input is given by:

$$S_{IN}\ (\text{dBm}) = S_T + G_T + G_R - L_{FS} - L_A - L_{WG} \qquad (3\text{-}6)$$

where

S_T = desired transmitted signal power (dBm)

G_T = transmitter antenna gain (dB)

G_R = receiver antenna gain (dB)

L_{FS} = free space loss (dB)

L_A = atmospheric attenuation (dB)

L_{WG} = waveguide loss (dB)

The interfering signal (I_{IN}) at the receiver input can also be expressed as:

$$I_{IN}\ (\text{dBm}) = I_T + G_T + G_R - L_{FS} - L_A - L_{WG} \qquad (3\text{-}7)$$

where

I_T = interference transmitted signal power (dBm)

It is also convenient to obtain the interfering signal from:

$$I_{IN}\ (\text{dBm}) = S_{IN} - (S/I)_{IN} \qquad (3\text{-}8)$$

Different threshold criterion can be chosen for $(S/I)_{IN}$ to obtain corresponding input interference criterion.

The input signal-to-noise can be obtained from Equation 3-5 and 3-6 as:

$$(S/N)_{IN} = S_{IN} - N_{IN} \qquad (3\text{-}9A)$$

$$= S_T + G_T + G_R - L_{FS} - L_A - N_{IN} \qquad (3\text{-}9B)$$

TYPE OF TESTS

In general, two types of tests (a closed-system test and an open-system test) are required to completely characterize the potential interference. The closed-system tests are done to provide a baseline for performance. They determine system response to known interference signal. These tests are run on the ground with an interference signal inserted directly into the receiving system along with the desired signal. In this way known levels of interference can be generated and the effects of this interference on the AGC, squelch, processing gain and signal quality can be made.

The first step in the closed test is to calibrate the AGC signal with a known input CW signal Next the input interference level is measured. Then the modulated desired signal is fed to the receiver along with the known interference. The $(S/I)_{IN}$ is varied and the $(S/I)_{OUT}$ is measured. Using Equation 3-2 the processing gain is derived and compared with measurements.

Following the closed-system test actual airborne open-system tests were made using an interference source in the test aircraft. These tests were done to confirm the predicted antenna coupling and microwave system interference. Since the interfering signal overlaps in frequency with the desired signal, it is not possible in the open-system test to directly measure interference power. However, from the baseline closed-system tests the input interference power level can be determined by measuring $(S/I)_{OUT}$. Since the processing gain was determined in the closed-system test, Equation 3-2 can be used to der've $(S/I)_{IN}$. Using this technique the S/I ratios were determined as the aircraft flew through the test area and radiated the potential interfering signal.

To simulate a 600 channel FM microwave system the baseband channel was noise loaded. A series of slots were notched out using 3 kHz slot filters. In this way the effect of the interference signal could be measured on the receiver by noting the rise in the noise in the slot. For the digital link and video link slots were available. The interference could be measured by noting the power rise in these slots.

FLIGHT PATTERNS

For the open-system test several flight patterns are used to investigate the possible antenna coupling. The first flight pattern consisted of inbound or outbound legs where the aircraft flew from over-the-horizon to directly over the terrestrial microwave station, trying to define the beam pattern of the terrestrial microwave.

The second series of flights were over-flights in the area of the terrestrial microwave system. These flights tested the overhead coupling of the terrestrial microwave system with the aircraft.

A third type of flights were an orbit pattern flown in the main beam of the terrestrial microwave system at a distance of 150 to 200 miles from the terrestrial microwave antenna. The purpose of these flights was to determine degradation from the worse case main beam coupling.

These three types of flight patterns provided samples of all possible mutual antenna coupling.

MEASURE OF DEGRADATION

The degradation experienced by a terrestrial microwave system depends upon the type of information being transmitted and the display or output equipment characteristics. For a 600 channel FM terrestrial microwave

system with diversity the degradation caused by an interfering signal appears as the squelching of one receiver channel as the interfering noise rises above a preset threshold.

If squelch or diversity are not available, the interference is noted as a rise in the baseband noise level as the interference increases. For a digital link the interference is measured as a change in the bit error rate.

For a video system the degradation is noted as a change in the video quality.

The FAA conducts air traffic control operations using both broadband and narrowband control systems. For the broadband system the display is a PPI scope. Degradation to the PPI display consisted of white wedges that mask the desired targets. For the narrowband control system the data is digital and the degradation experienced is an increase in the error rate.

ANTENNA PATTERNS

A variety of antennas are used for the various terrestrial microwave links. The patterns of these ground antennas are similar. Therefore, for the purpose of this report a standard ground antenna pattern has been used. This pattern (Figure 2) shows the predicted antenna gain for a parabolic antenna and for the periscope antenna which uses a dish at ground level radiating up to a passive reflector on the tower.

The airborne antenna pattern is influenced by the direction the antenna is pointed relative to the nose of the aircraft. After a series of antenna measurements (Appendix A) an envelope antenna pattern was established as shown in Figure 3. This pattern describes the peak gains measured for various angles off the main beam.

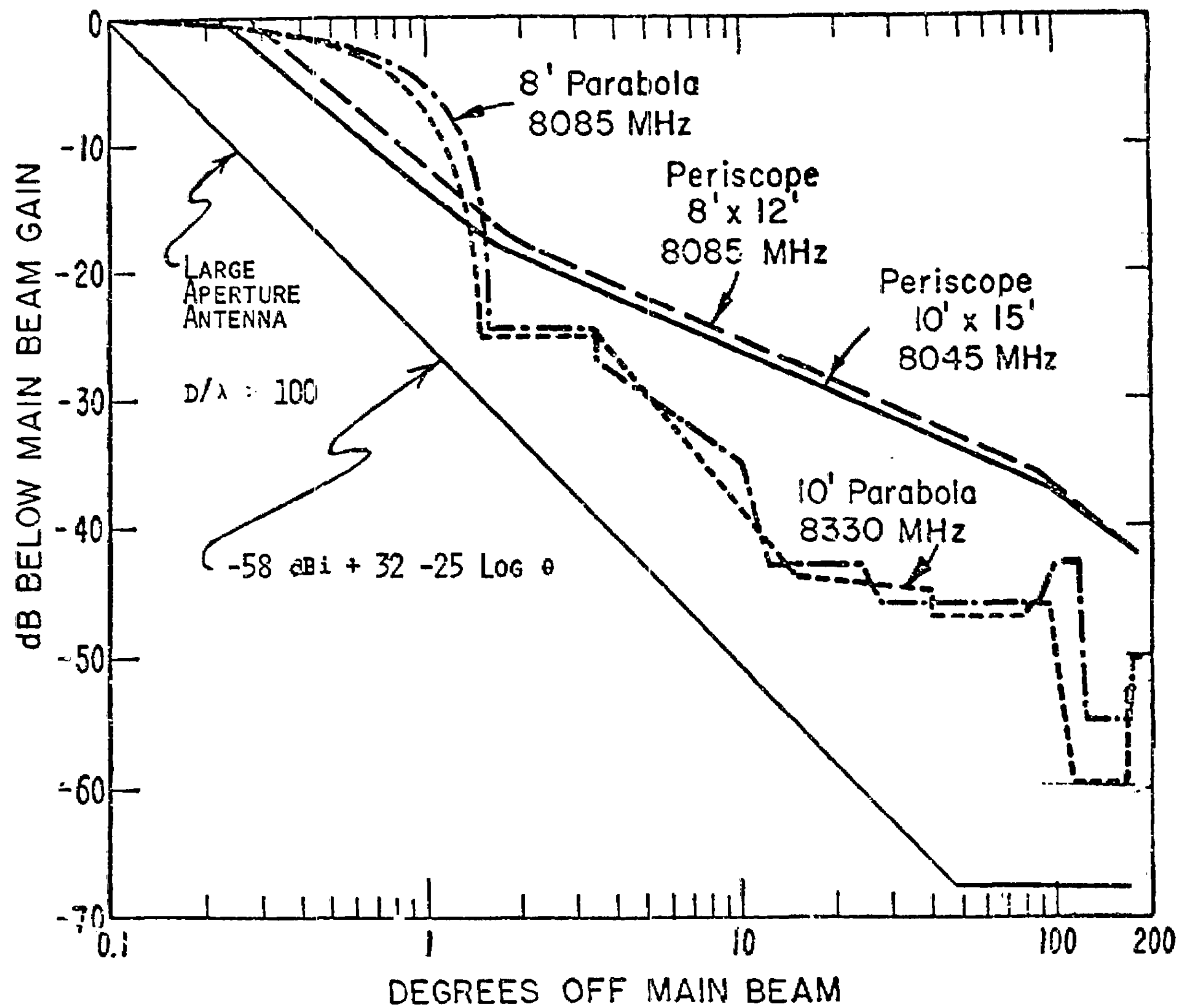


FIGURE 2 GROUND ANTENNA MODEL

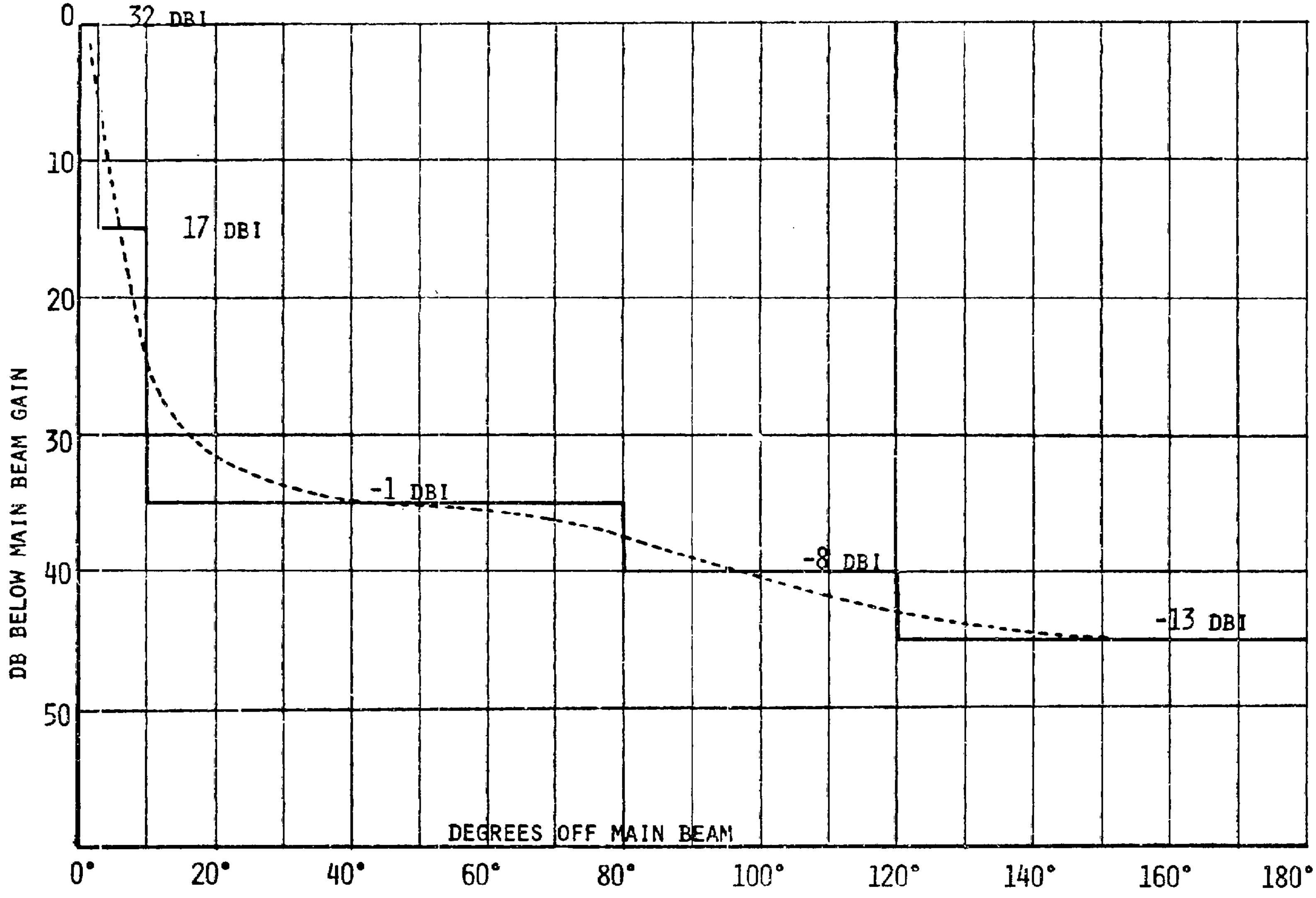


FIGURE 3 AIRCRAFT ANTENNA MODEL

ATTENUATION

The attenuation value used in the calculations of this report include both free space and atmospheric attenuation effects. The free space curves for a ground-to-air microwave system are shown in Figure 4. This figure shows that free space can be used at distances of 200 miles or less.

Atmospheric attenuation was derived from the material presented in Reference 17. The results are shown in Figure 5 and are used in the system calculations.

EFFECTS OF FADING

Terrestrial microwave systems may experience signal fading due to several causes.[18,19] During a signal fade the terrestrial microwave system may be more vulnerable to interference. However the susceptibility depends upon the cause of the fading.

Ducting or inversion layers can cause fading. However, ducting or inversion layers are more likely to occur between the aircraft and the terrestrial terminal, thereby providing additional shielding rather than additional interference.

The effect of rain cell attenuation between terrestrial microwave transmitter and receiver will cause the same or greater attenuation of the aircraft interfering signal. Therefore, fading due to rain cell attenuation should not affect the signal-to-interference ratio generated by the airborne interference.

Multipath fades may result from gradual changes in refractive index along the propagation path, especially during the evening or morning hours. The fades between the two terrestrial terminals are not expected to be correlated with the multipath fades between the aircraft and the terrestrial receive terminal. Therefore, the terrestrial link will be more susceptible to interference during periods of multipath fading.

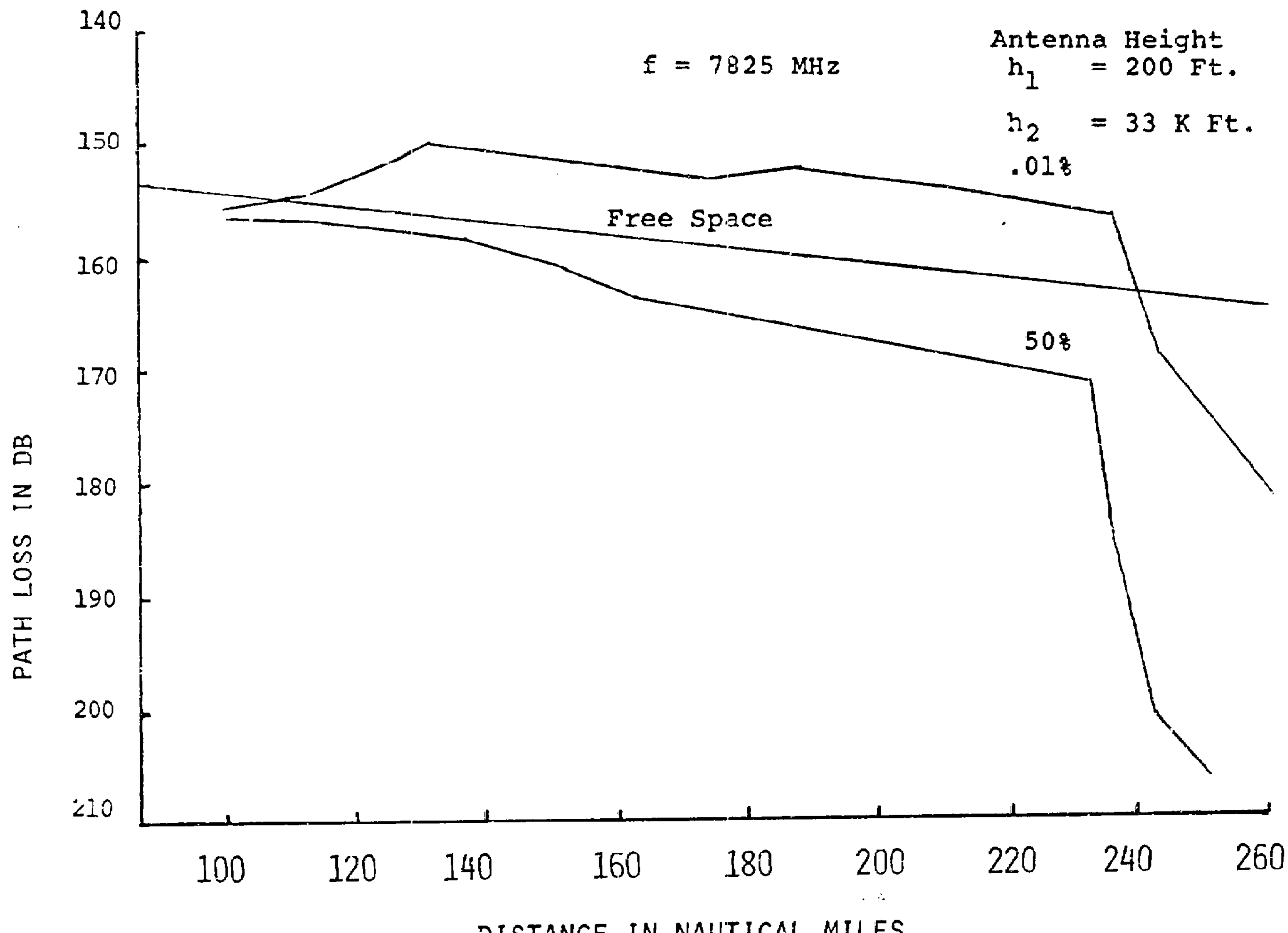


FIGURE 4 FREE SPACE PROPAGATION LOSS FOR AIR-TO-GROUND PATH

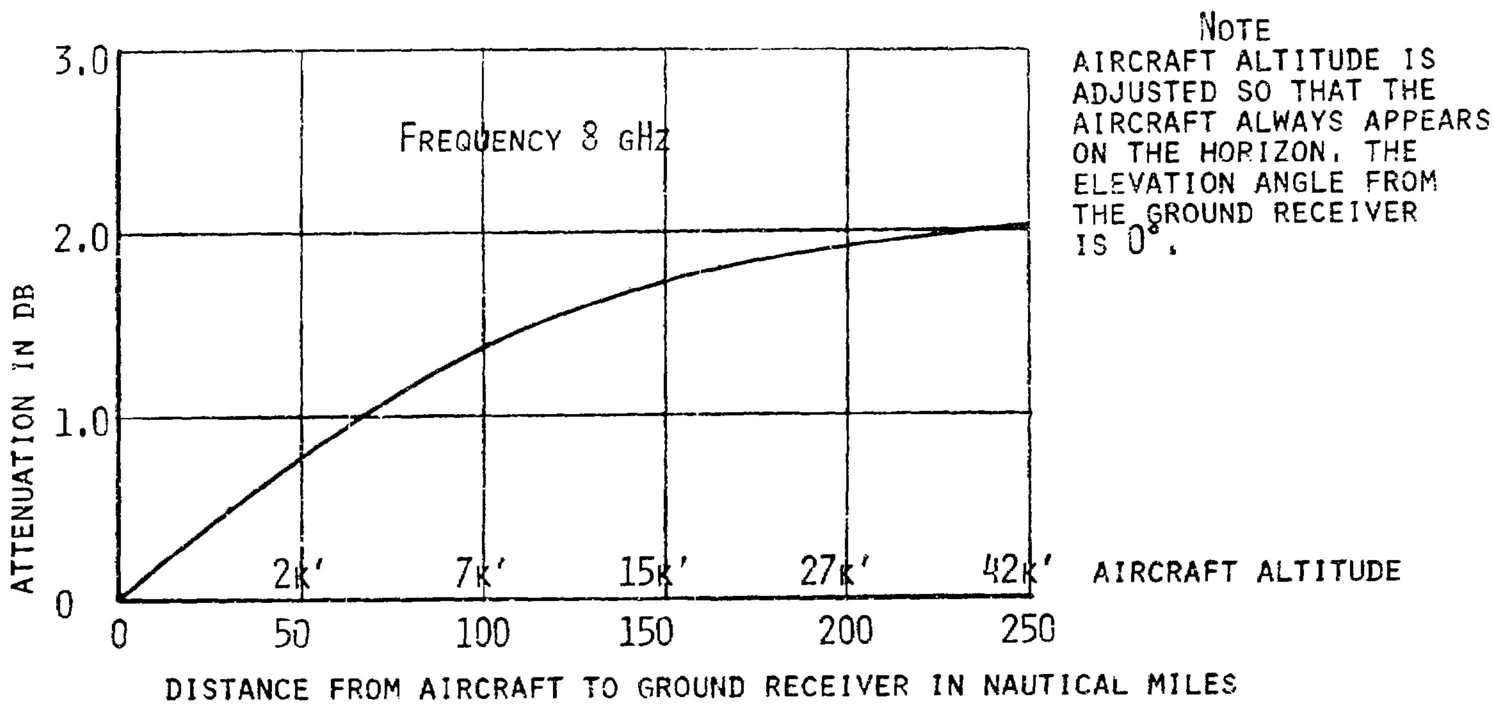


FIGURE 5 ATMOSPHERIC ATTENUATION FROM AIRCRAFT TO GROUND RECEIVER

SECTION IV

SHF SATCOM OPERATIONAL CONSIDERATIONS

INTRODUCTION

The E-4 is being implemented to provide a survivable DOD command center. One use of the E-4 is to support the National Emergency Airborne Command Post (NEACP) operating presently out of Andrews Air Force Base, Maryland. NEACP has the responsibility of providing an emergency command and control system which the National Command Authority (NCA) can use to direct military forces in the time of a national emergency. The other use of the E-4 is the operation of the Command-in-Chief of SAC. The SAC command post operates out of Offutt Air Force Base, Nebraska to provide directions to the worldwide SAC forces in time of emergency.

The E-4 system is presently in the initial implementation phase. Only one test aircraft is expected to be equipped with the SHF SATCOM system by 1978. Additional aircraft will probably not be equipped prior to 1980. Even when all six E-4 aircraft are equipped with the SHF SATCOM system, only two are likely to be flying at any one time.

FLIGHT PARAMETERS

The normal flight routes of the NEACP aircraft in peacetime can be anywhere in the United States. They normally fly direct point-to-point, but may fly airways. The flight altitudes are from 24 to 35 thousand feet. The normal peacetime flight orbit for the SAC airborne command post is in the area around Offutt AFB which covers portions of Nebraska, Iowa, Minnesota and South Dakota.

Prior to completion of this report it was not possible to determine the planned maximum transmit power level, time or duration of SATCOM operations. Therefore, the results of this report are structured to allow the users of the E-4 or others to evaluate the effect of various transmit power levels or transmit duration on the probability of causing interference.

SHF SATCOM PARAMETERS

The airborne SHF SATCOM system (ASC-18) has been designed to provide a reliable jam-resistant communication system for high priority traffic between E-4's and other airborne or ground command centers. The ASC-18 utilizes a 10 kW transmitter and a 32 dB gain parabolic antenna to achieve a high effective radiated power to overcome potential jamming threats. The ASC-18 receiving system utilizes the 32 dB gain dish and a low noise parametric amplifier to provide a sensitive receiving system. The SHF antenna can be passively pointed towards the satellite using a computer pointing group which converts the satellite ephemeris and directional information from an inertial navigation system into a pointing vector.

An active tracking capability also exists where the antenna senses downlink energy from a beacon signal transmitted by the DSCS-II satellite. The ASC-18 interfaces with the modulation/demodulation system at a 70 or 700 MHz interface. Appendix B more fully describes the ASC-18.

MODULATION

The planned modulation system for the E-4 is a USC-28 pseudo noise (PN) modem. This modem utilizes band spreading to achieve jam protection. This protection is provided by spreading the relatively low data rate of the information signal to be transmitted over a 40 MHz

bandwidth using direct sequence pseudo random noise. The basic modulation/demodulation technique is phase-shift keying.

A narrowband FM voice modulation may be used for test coordination purposes over the satellite. Since the interference of a narrowband FM is similar to that of CW, it was decided to include CW modulation in the interference test.

DSCS SATELLITES

The SHF satellite to be used initially is the DSCS-II satellite. These satellites operate on the uplink frequencies of 7.9 to 8.4 GHz. The satellites have an earth coverage horn-type antenna and a spot-beam or narrowbeam parabolic antenna. The 500 MHz uplink band is broken into four satellite bands which are from 50 to 185 MHz wide, as shown in Figure 6. By proper selection of frequencies the uplink signal can be received and retransmitted from the following combinations of bands: receive earth coverage, transmit narrowbeam; receive earth coverage, transmit earth coverage; receive narrowbeam. transmit earth coverage; receive narrow beam, transmit narrowbeam.

An exclusive satellite band has been established in the 7.975 to 8.025 GHz uplink band. This falls within the earth coverage - earth coverage mode of the DSCS-II.

The DSCS-II satellites are in a synchronous equatorial orbit. The two satellites in operation at this time are located at 13°W 0°N (#9433) and 175°E 0°N (#9434).

Other Phase II satellites are planned with one to be located at 135°W. Coverage of the Phase II satellites at 135°W and 13°W are shown in Figures 7 and 8.

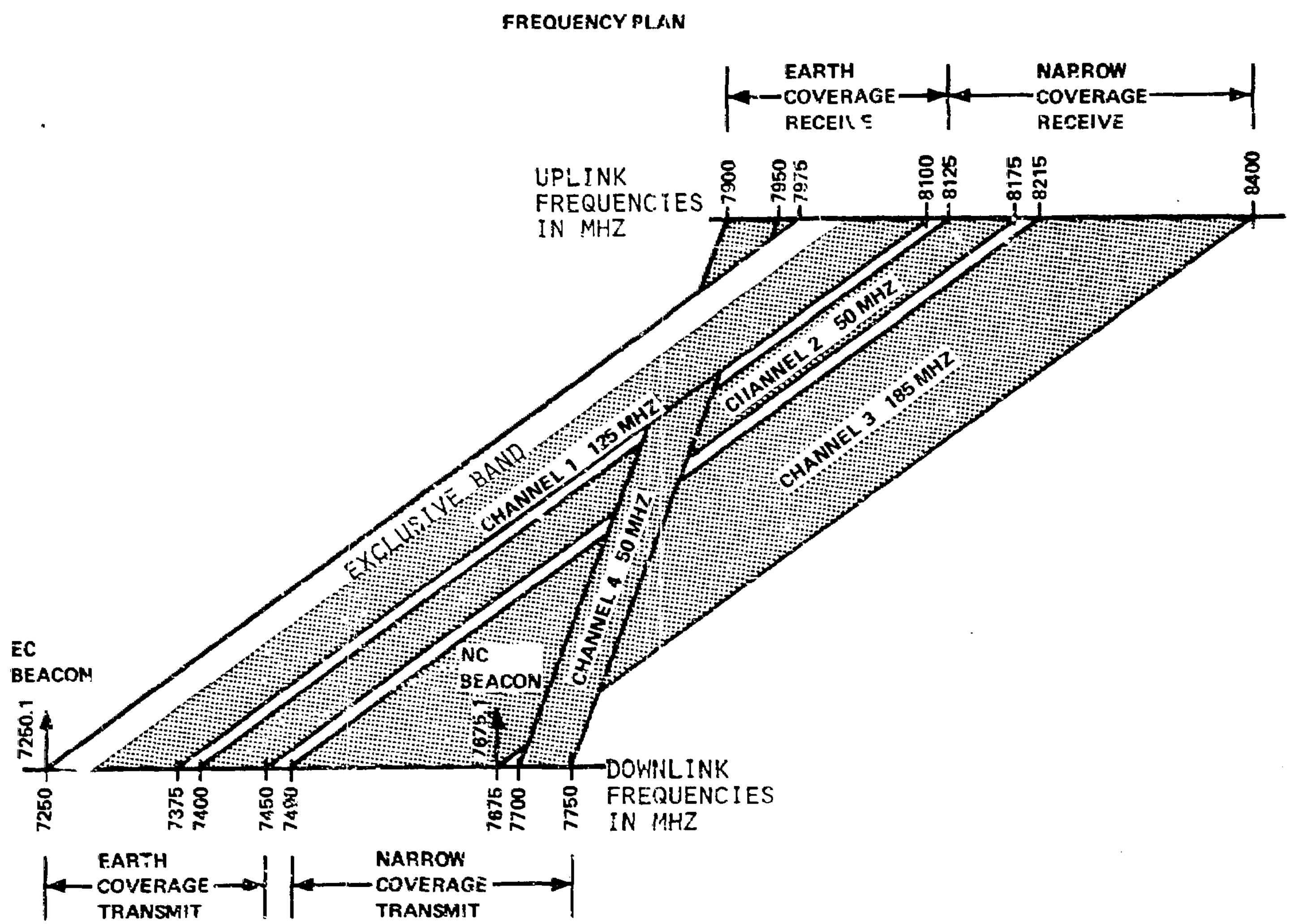


FIGURE 6 DSCS II SATELLITE FREQUENCY PLAN

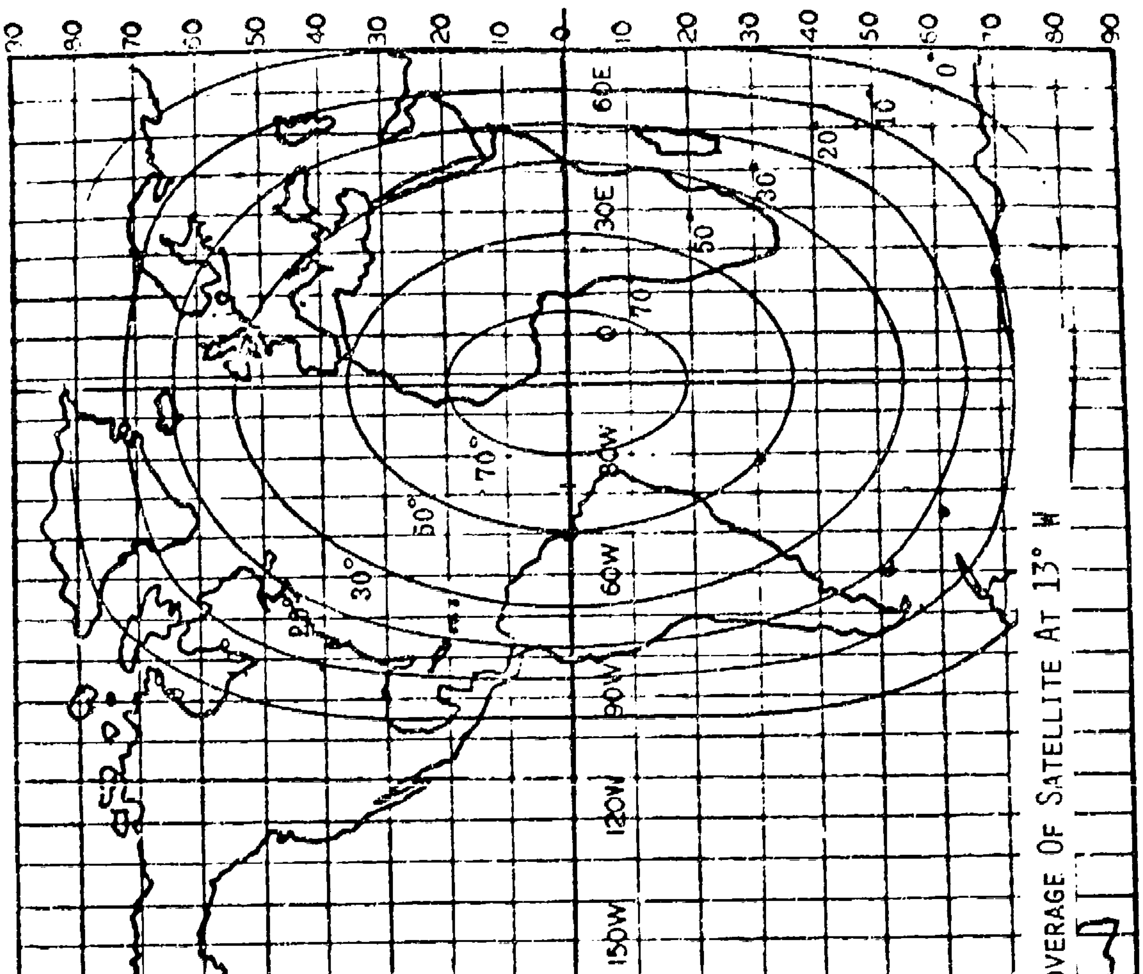


FIGURE 7 COVERAGE OF SATELLITE AT 13° W

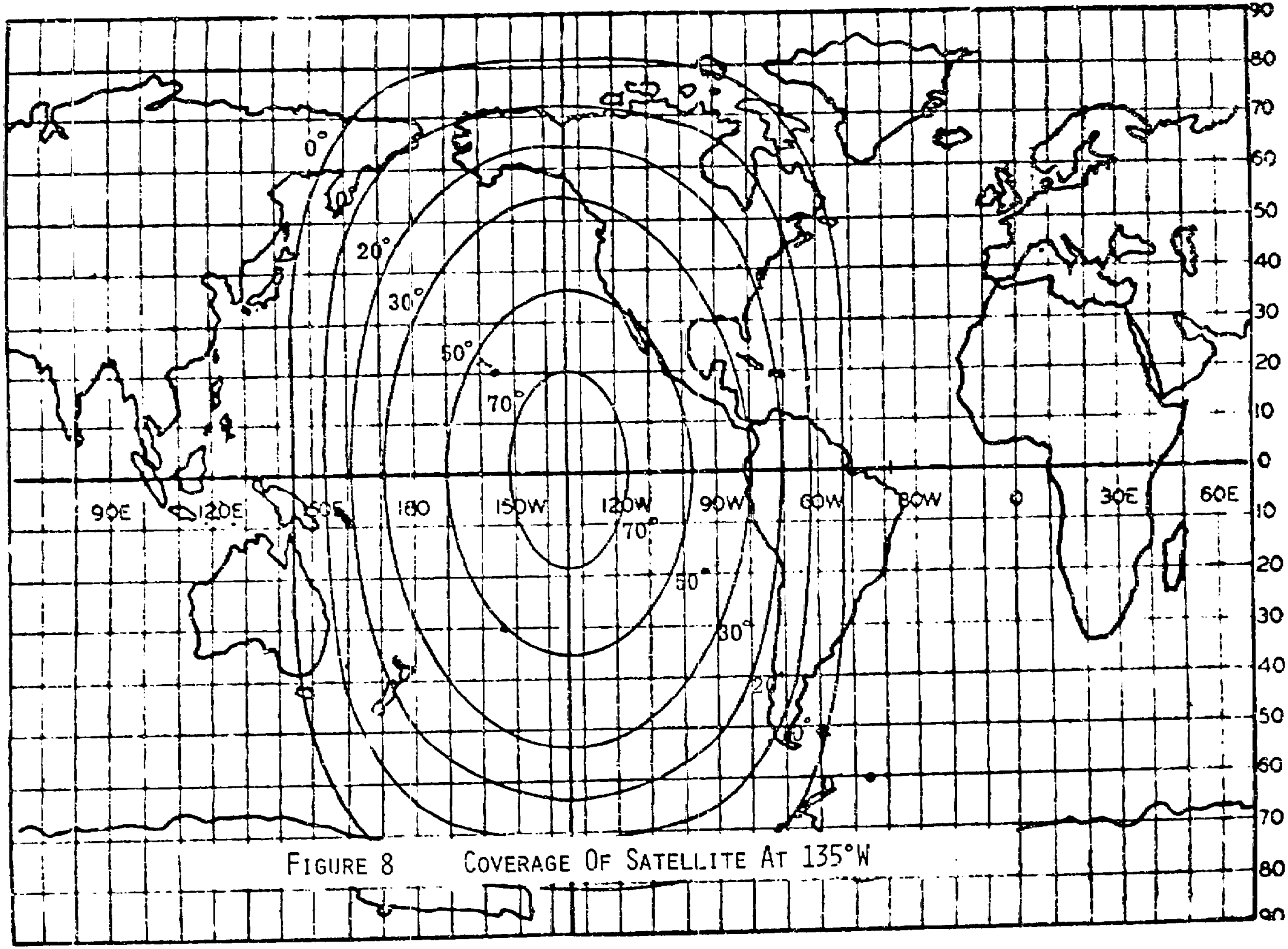


FIGURE 8 COVERAGE OF SATELLITE AT 135°W

By approximately 1980 the third phase of the Defense Satellite Communication System (DSCS-III) is expected to be in operation. For these satellites a different frequency plan is being selected which allows operation of the narrowbeam - narrowbeam mode in the exclusive band (7.975-8.025 GHz uplink).

FREQUENCY

While the E-4 will have the capability of operating its airborne SHF SATCOM terminal on any frequency within the 500 MHz satellite authorization, the present plans are for normal operation to be at the narrowbeam - narrowbeam or narrowbeam - earth coverage frequencies. For DSCS-II the planned uplink frequencies [8.215-8.265 GHz (NB-NB), 8.125-8.175 GHz (NB-EC)] are in the shared part of the band For the planned DSCS-III the narrowbeam - narrowbeam capability will be available in the exclusive band which should minimize the interference problem.

SECTION V

TENNESSEE VALLEY AUTHORITY/BONNEVILLE POWER ADMINISTRATION MEASUREMENTS AND ANALYSIS

INTRODUCTION

This section summarizes the results of the theoretical and experimental studies conducted by the SHF SATCOM Interference Study Group as they apply to FDM/FM 600 channel microwave links. Earlier theoretical studies concluded, based upon parameter values available at the time, that it was likely that the airborne SHF SATCOM terminal radiation would exceed the minimum signal-to-interference threshold while the aircraft was within the main beam of the microwave station antenna. And it was further determined that this could occur while the microwave signal was not fading. An additional study was undertaken to determine what impact this type of interference would have based upon the probability of its occurrence.[2,14,20]

Concurrent with these studies, a measurement program was undertaken to verify the theoretical interference criteria and to refine and define some of the parameter values which previously had to be estimated.

The measurement program results are reported in detail in Reference 5 and 7, and are summarized here for the particular areas which apply to the FDM/FM 600 channel type systems.

SYSTEM DESCRIPTION

The general type of system to be considered is a multichannel frequency division multiplexed frequency modulated point-to-point communications system.

These systems transmit voice, analog and digital data over standard 3.1 kHz wide audio channels. The individual channels are multiplexed

together in groups of from 12 to 1200 to form a baseband of frequencies which then frequency modulates the carrier for transmission.

While the individual systems may vary slightly in their noise and RF/IF bandwidth characteristics, the information bandwidths, modulation and signal levels, which are the controlling factors for interference analyses have been standardized through the recommendations of the CCIR and the DOD standards. These standards are adhered to quite rigidly in practice, and will be used here to determine the typical system characteristics for use in the analysis. The performance of a microwave system can be measured in terms of processing gain (PG). This is given by Equation 3-2:

$$PG = (S/N)_{OUT} - (S/N)_{IN} \quad (5\text{-}1)$$

The test program derived PG values for the types of interference which the airborne SHF SATCOM system can generate. The Tennessee Valley Authority made the McEwen, Tennessee operational link available for testing. That system is typical of the equipment operating in this band.

The TVA link tested was an 18.8 mile hop from Johnsonville (Site 1) to McEwen (Site 2), Tennessee. The equipment at both stations is Collins 508D RF with a MX 106 multiplexer. The link is clear from obstructions and antennas are aimed on the horizontal.

The McEwen receiver uses an eight foot Andrews P8-71G dish mounted 100 feet up on a 140 foot tower. The desired signal strength at the McEwen receiver computed by TVA is -33.8 dBm including all waveguide and coupler losses. This provides a fade margin of 40.2 dB as calculated in TVA drawing LC-92968 R-1 Sheet 9.[21] The RF input noise level of the Collins 508D is specified at -88 dBm. This would provide TVA with a minimum signal-to-noise of 14 dB $(S/N)_{OUT}$ in the 508D's baseband channel while

experiencing a 40.2 dB fade. The average signal strength during the testing was -35 dBm.

GROUND TESTS

General - The object of the ground test was to measure in a closed link system configuration basic receiver characteristics required for the interference analysis and the airborne SHF SATCOM terminal test. The ground tests were first conducted on 2-4 October 1974[5] and repeated on 3-7 March 1975 along with the airborne tests.[7]

The block diagram used in the test is shown in Figure 9. The figure indicates the test configuration used for the 70 kHz, 1.248 MHz or the 2.438 MHz channels of a typical 600 channel TVA system. In this test configuration, the signal to be interfered with has baseband slot filters introduced one hop (Site 1) before the site at which the interference was introduced (Site 2). At Site 2, the input interference power levels and the corresponding output slot noise interference power levels were measured. The AGC voltage was measured to obtain a calibration of the input desired signal level. The critical control voltage (CCV) was measured to obtain a calibration of the squelch point. The desired output signal level is obtained from calibration measurements in which the proper level of the desired signal was introduced at Site 1 and measured at the output of Site 2. Sufficient information was available to obtain the relationship between the input and output signal-to-interference power ratio and therefore obtain the processing gain (PG) of the system. The output AGC voltage and the CCV was measured as a function of the input inteference signal level.

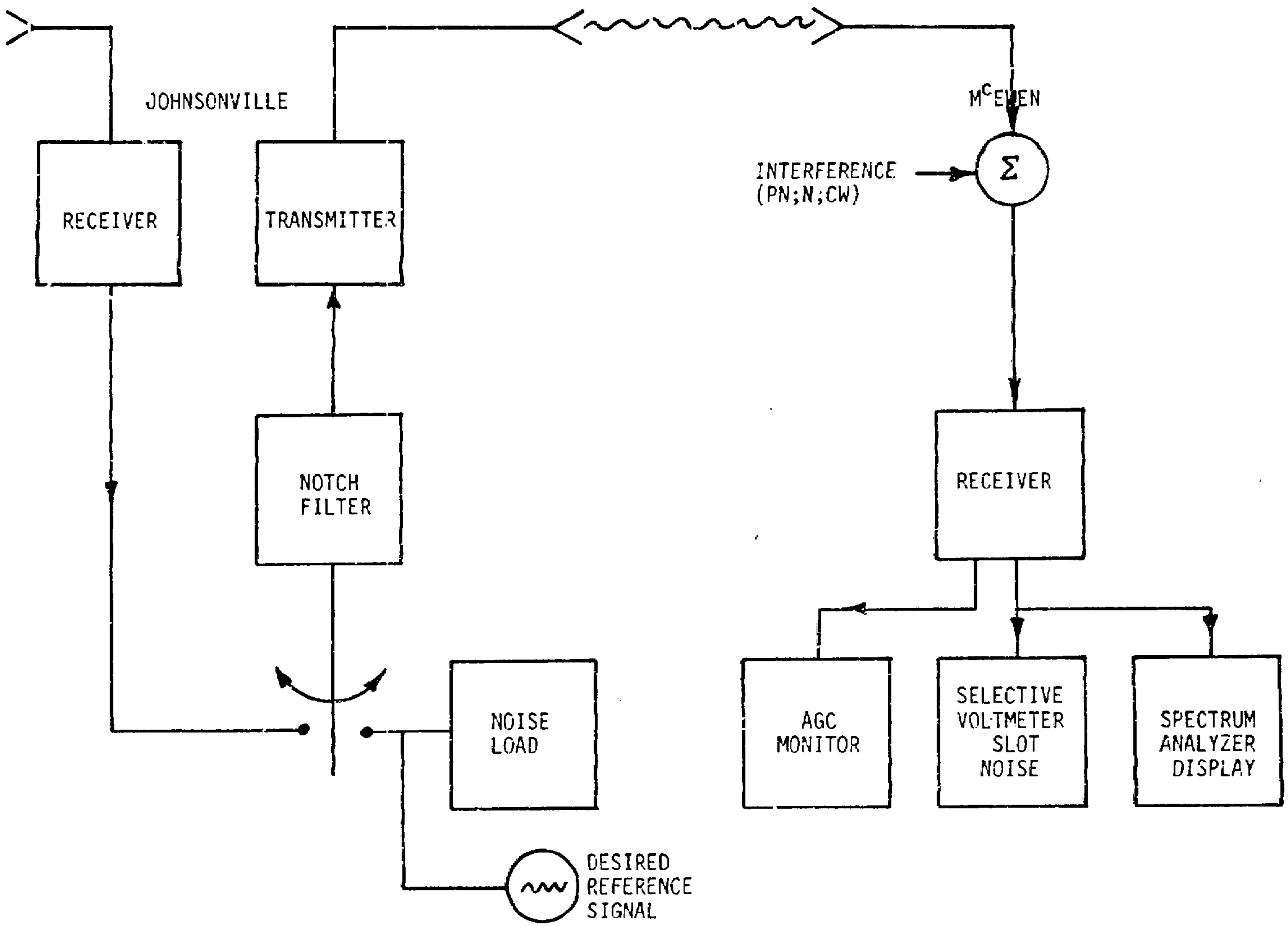


FIGURE 9 TVA GROUND TEST EQUIPMENT SETUP

The receiver characteristics measured in the ground tests for the TVA system were:

1. AGC and CCV
2. Quieting slot noise
3. Slot interference power for a Noise loaded baseband (PN, N or CW interference)
4. Squelch criteria
5. Off frequency rejection

The following describes the results of these measurements.

AGC, CCV Characteristics - The AGC and CCV characteristics of the test TVA receiver are shown in Figure 10. The characteristics were measured during two separate measurement periods. The IF amplifier was changed between the two measurement periods resulting in two different sets of AGC relationships. The data shown was from the March measurement period since this data was used in conjunction with the airborne measurements. The AGC curves were mainly used to calibrate the desired input signal level in all of the subsequent slot noise interference tests. They were also used in the airborne antenna tests to indicate a received input CW signal power level when the TVA microwave signal has been turned off.

Quieting Slot Noise - The quieting slot noise curves for the TVA receiver are shown in Figure 11. These curves were obtained by injecting an unmodulated desired signal (CW) and measuring the noise in a slot. Ideally, this noise is directly proportional to frequency squared and inversely proportional to the CW carrier level. For these measurements it was specified that the receiver front end noise level was -88 dBm. Consequently, instead of the input CW carrier level, input signal-to-noise ratio was plotted. Repeated measurements of these curves were made during two separate periods. The

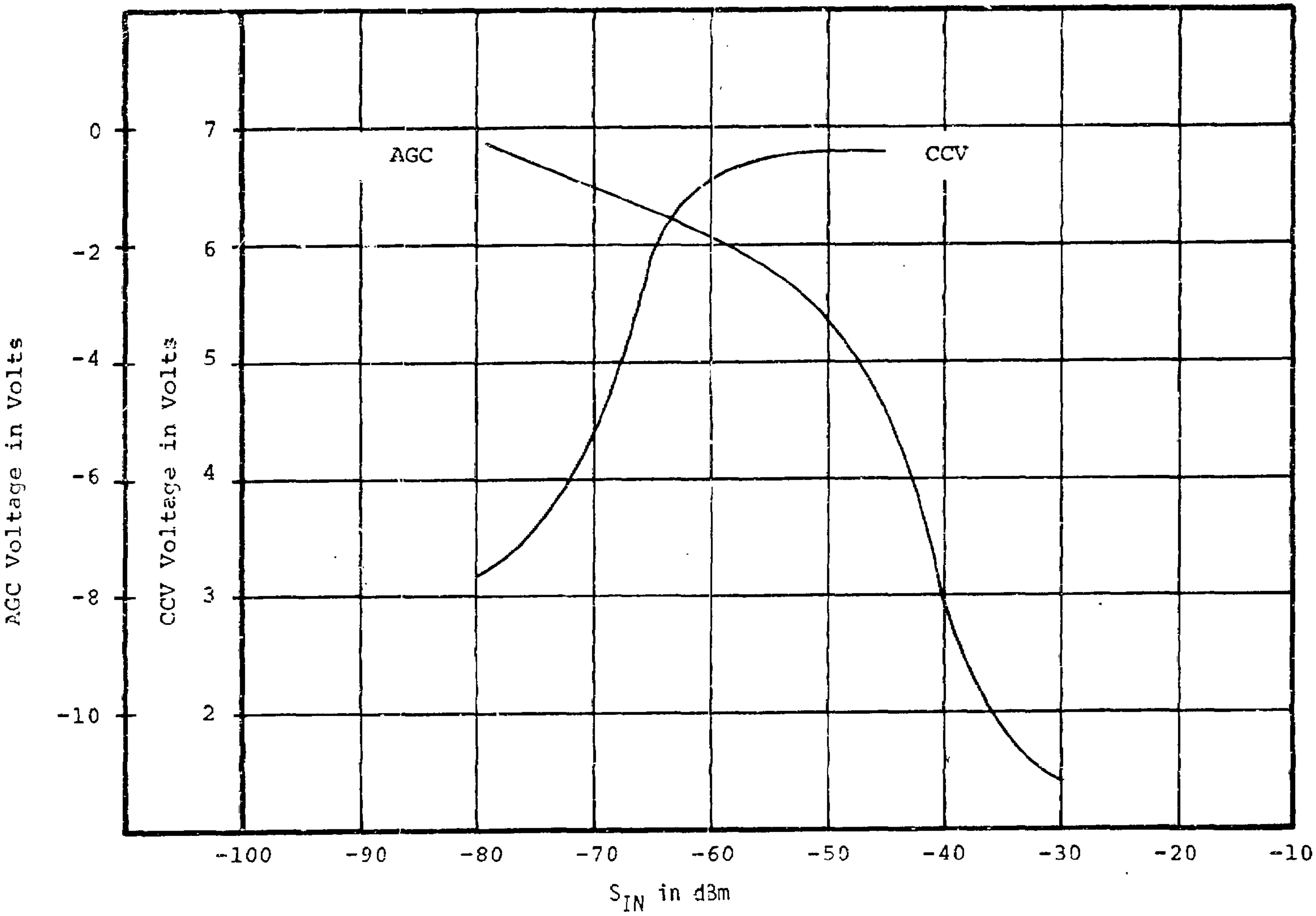


FIGURE 10 TVA AGC AND CCV CHARACTERISTICS

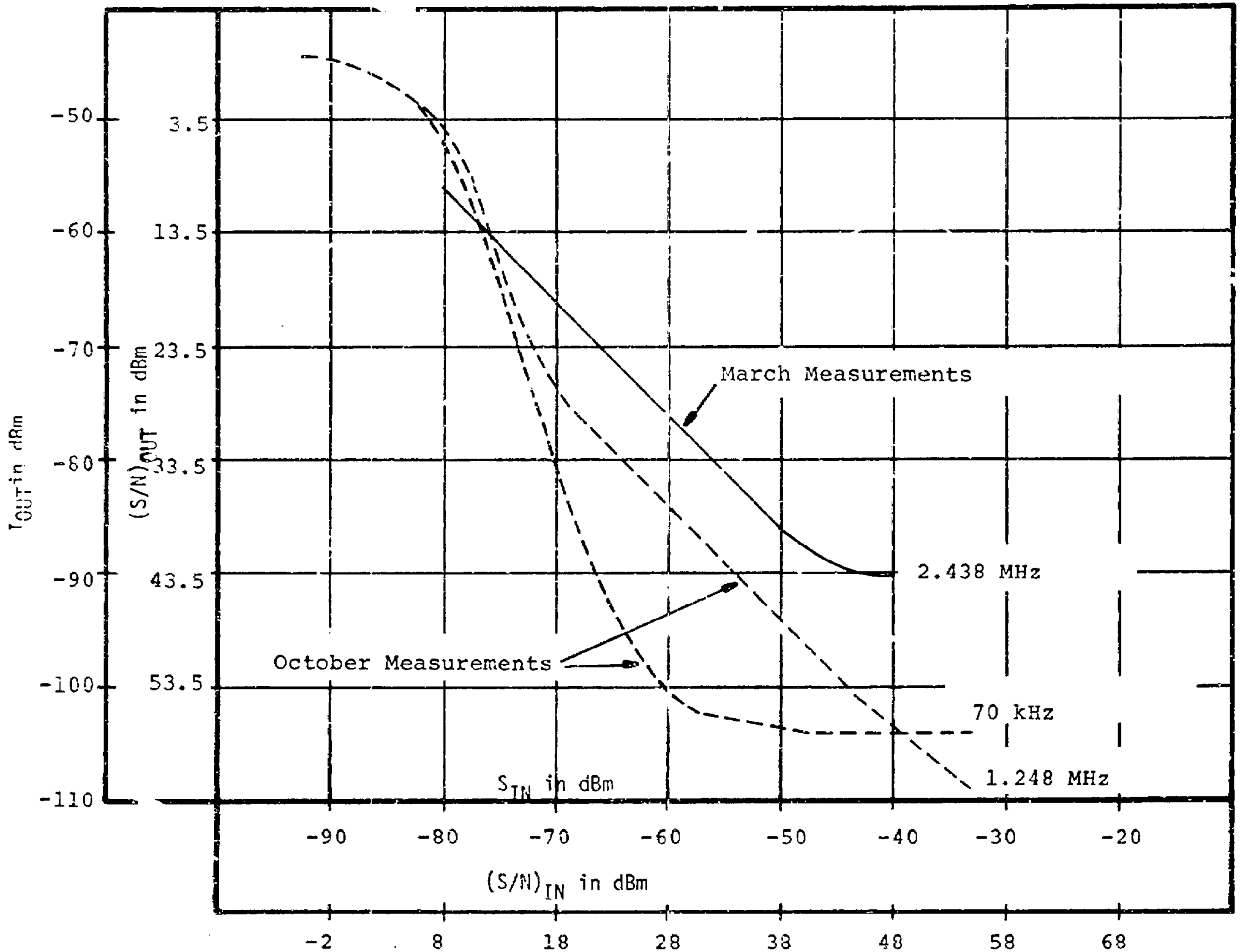


FIGURE 11 TVA SLOT NOISE QUIETING

curves show the 70 kHz, 1.248 MHz and the 2.438 MHz slot noise and total baseband output noise as a function of desired input signal power. The straight 1:1 slope of the 1.248 MHz and the 2.438 MHz curves indicate the linear operating region of a good receiver. The curved region of the 70 kHz curve indicates the large distortion typically encountered in the lower channels. If the higher frequency slot noise curves were not linear over a large portion of their operating region, the interference slot noise measurements (these will be described in the next section) would also not be linear and this would have increased the error in subsequent interference measurements. The 1.248 MHz and the 2.438 MHz curves shown in Figure 11 were linear in the normal operating region and, therefore, indicate good operating receivers. The curves indicate non-linearities for very weak and strong desired signal levels which is also normal receiver operation.

Figure 11 also indicates the output signal-to-noise ratio. This was obtained by introducing a noise modulation level at the transmitter proportional to 200 kHz and recording the output receiver signal level (-46.5 dBm). The ratio in a slot is then the ratio of desired noise power to f^2 noise. The processing gain, as defined by Equation 5-1, for a 2.438 MHz channel with noise modulation (NM) was measured as:

$$PG_{NM} = 24 - 22 \text{ dB} = 2 \text{ dB}$$

Converting this Noise Power Ratio type of PG to a tone signal-to-noise, we need to add the conversion shown in Figure 12. In addition to this factor a filtering factor for the noise should also be considered. The slot noise measurements were made with the HP filter shown in Figure 13.

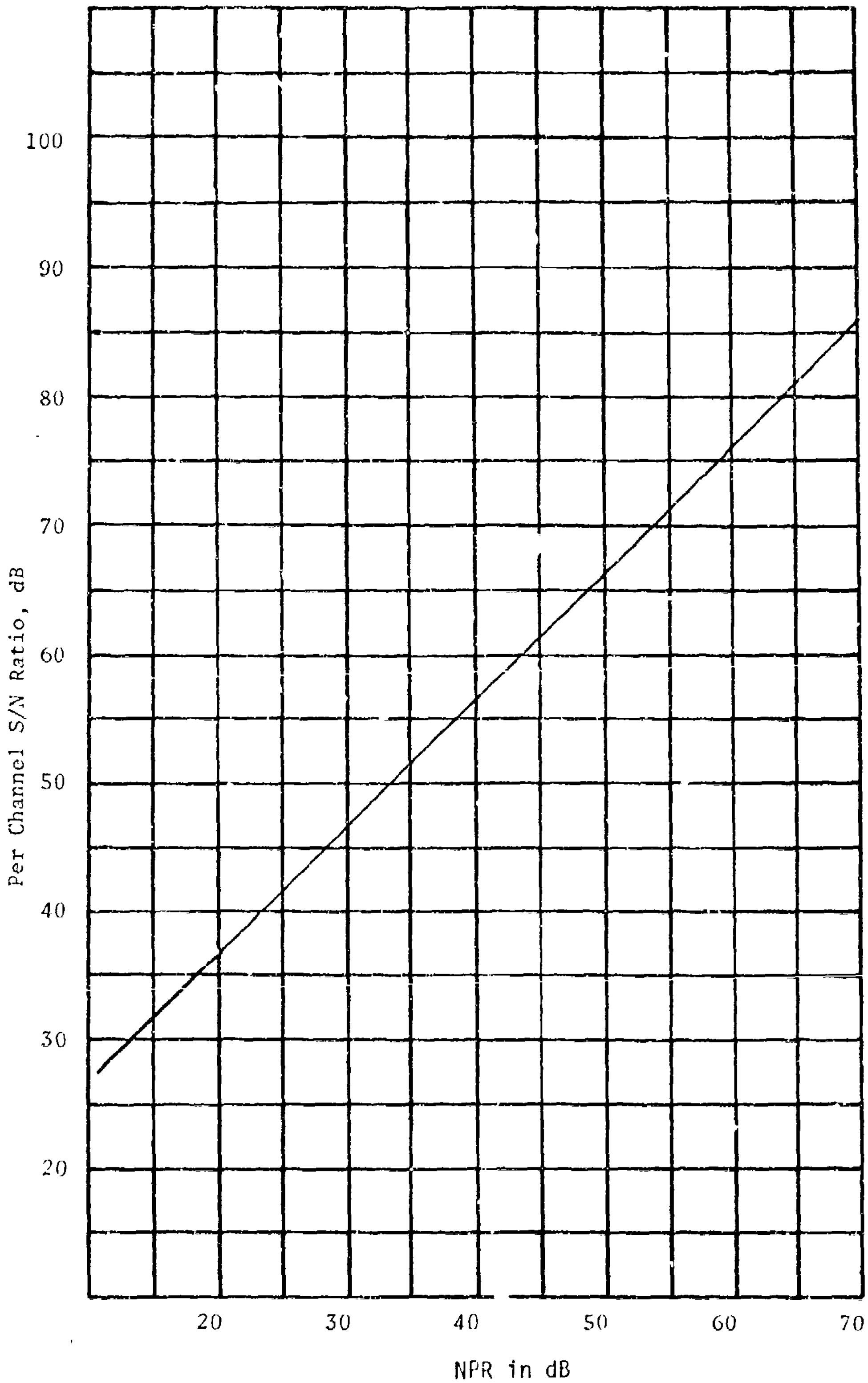


FIGURE 12 NOISE POWER RATIO VERSUS $(S/N)_{OUT}$

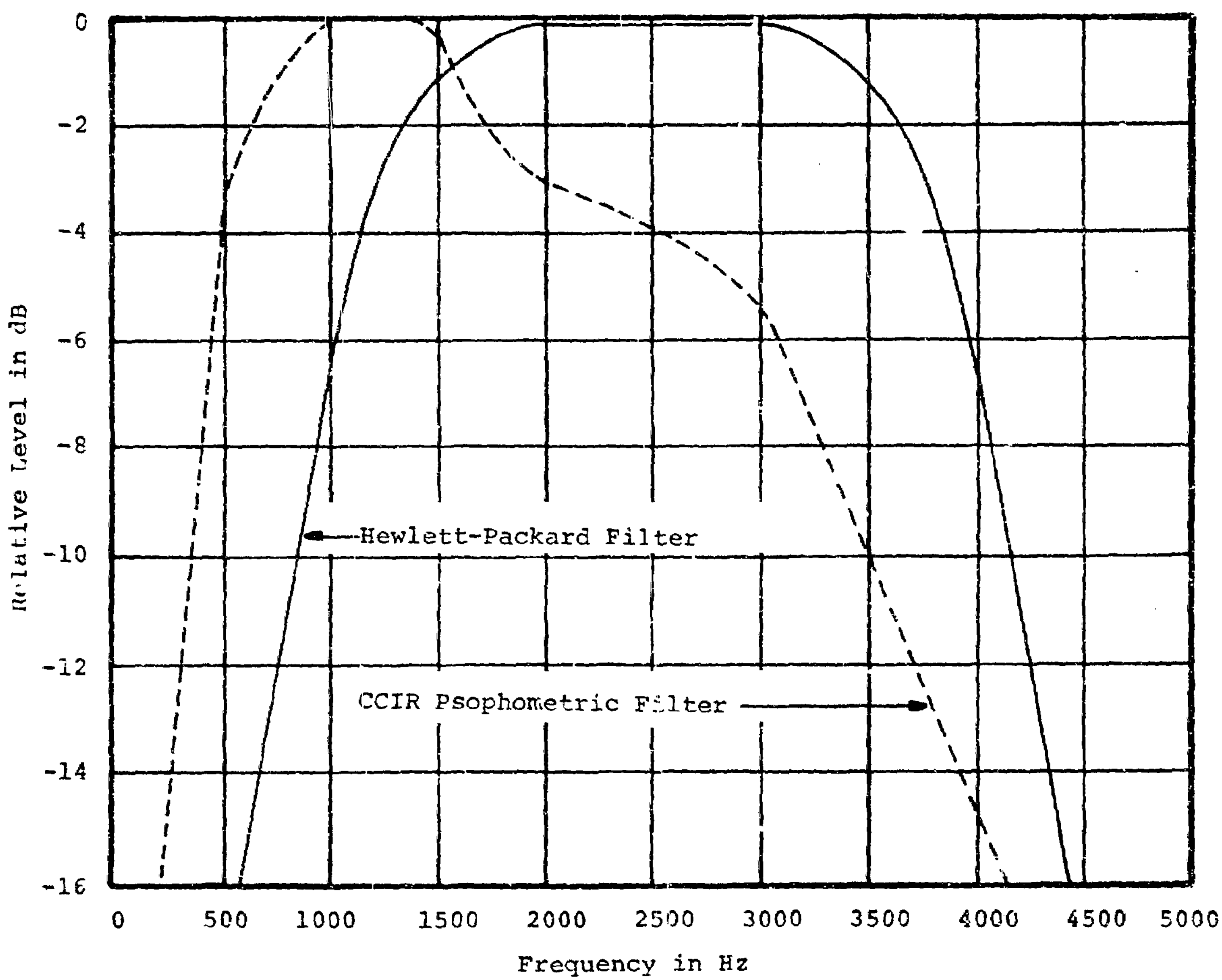


Figure 13 Filter Characteristics

This filter is shown in comparison with the CCIR psophometric filter which has a 2.5 dB filtering reduction above white noise. The HP filter was calculated to have a .9 dB filtering effect. The processing gain for white noise quieting (NQ) is then obtained as:

$$PG_{NQ} = PG_{NM} + 16 \text{ dB} - .9 \text{ dB} = 17.1 \text{ dB} \qquad (5.2)$$

The theoretical PG is obtained from Equation 3-3:

$$PG_N' = \left(\frac{200 \text{ kHz}}{2438 \text{ kHz}}\right)^2 \frac{22000 \text{ kHz}}{3.1 \text{ kHz}} \rightarrow 16.7 \text{ dB} \qquad (5\text{-}3)$$

The measured PG therefore agrees closely with the theoretical PG. This value will be used in the next section to compare with pseudo noise and the noise interference case.

Slot Interference Power for a Noise Loaded Baseband - The most important ground test interference measurements made for the airborne SHF SATCOM terminal tests were the slot noise measurements that indicate the degradation of a receiver output channel as a function of the input interference power. Without these measurements it would not be possible during the flight test measurement to know the signal strength of the undesired signal source. This is because the desired FM microwave signal and the undesired signal have overlapping spectrums and cannot be separated with a spectrum analyzer at the receiver input. This type of information is not specifically required for the closed system tests since the desired and undesired signal power can be measured directly at the output of the respective signal generators or input to the receiver.

The slot noise measurements or the measurements of the power in a particular baseband frequency slot can be obtained with a fully loaded or a lightly loaded baseband. Most multiple channel FM systems heavily use

all channels and consequently the baseband loading can be simulated by noise loading the baseband. The TVA channels vary in loading from light to heavily loaded. The full noise loading measurements were done so that the TVA system could be generally compared with FAA, AEC or other fully loaded systems. The TVA noise loaded receiver measurements are shown in Figures 14 and 15. These are shown for three representative voice slots (70 kHz, 1.248 MHz and 2.438 MHz) and three types of interference (PN, Noise and CW). These curves and all subsequent curves are plotted as a function of the input signal-to-interference power ratio $(S/I)_{IN}$ and both the output slot noise and the noise power ratio (NPR). The original measurements were taken with specific interference and desired signal levels. Since the microwave carrier signal level varies with fading and from one location and/or equipment type to another, the curves have been normalized as a function of the $(S/I)_{IN}$ ratio so that the results are directly applicable to all similar types of microwaves providing the desired signal level is known. The curves show good linearity for the upper voice slots for the PN and Noise interference. The lower 70 kHz slot shows the typical lower channel non-linear effects due to intermodulation as was indicated in the previous quieting measurements. Since the 2.438 MHz slot will be used as the main monitor or reference channel, no calibration problems will be encountered since this is a reasonably linear channel.

The measured channel PG values were compared with the theoretically calculated values. The processing gain of the channels can also be calculated and compared with the measurements. The processing gain of a multi-channel FM is given by Equation 3-3 and was found to be 16.7 dB for the particular 600 channel system being examined. The measured PN, N and CW processing gain are found to be:

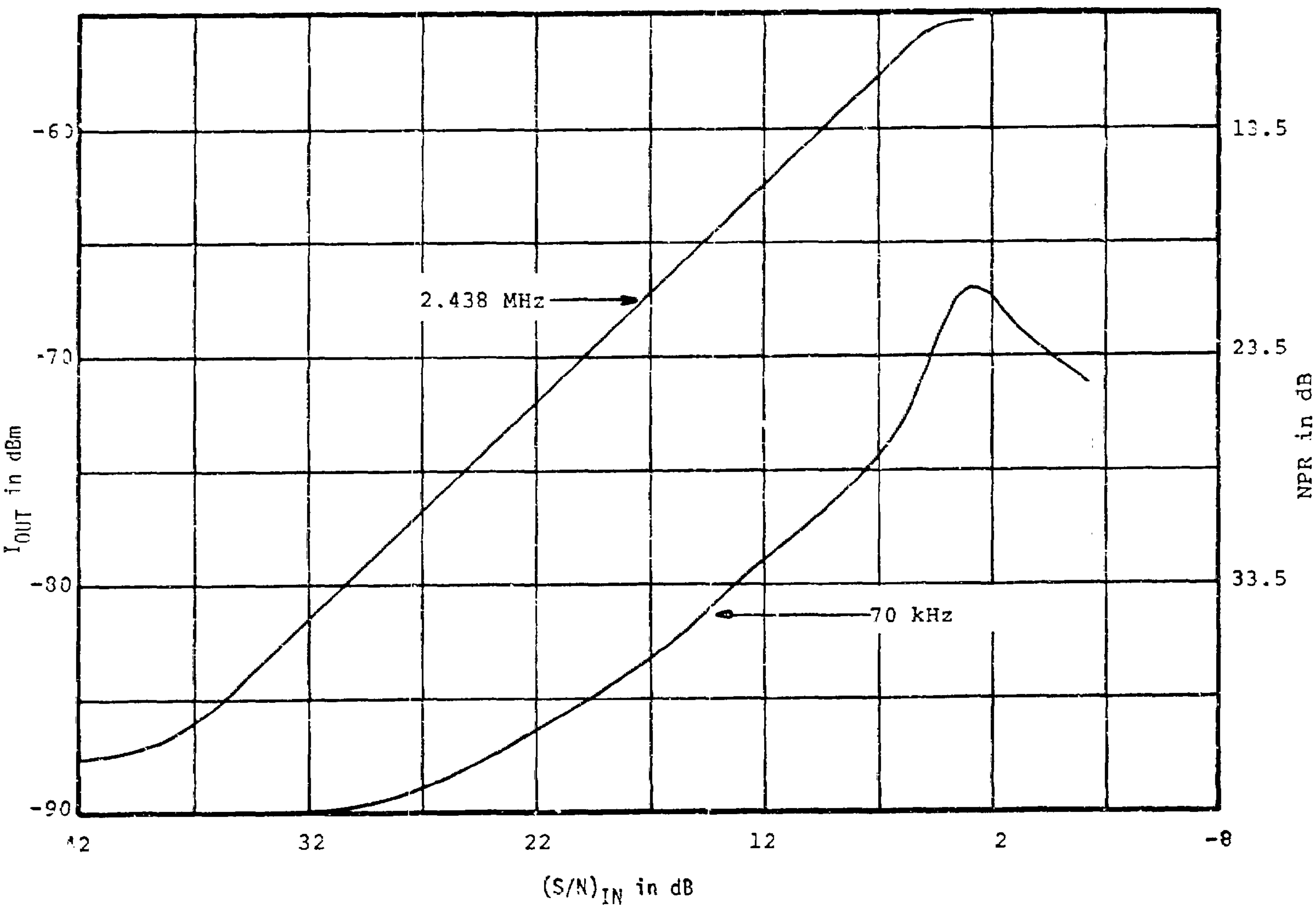


Figure 14 Slot Noise versus CW Interference

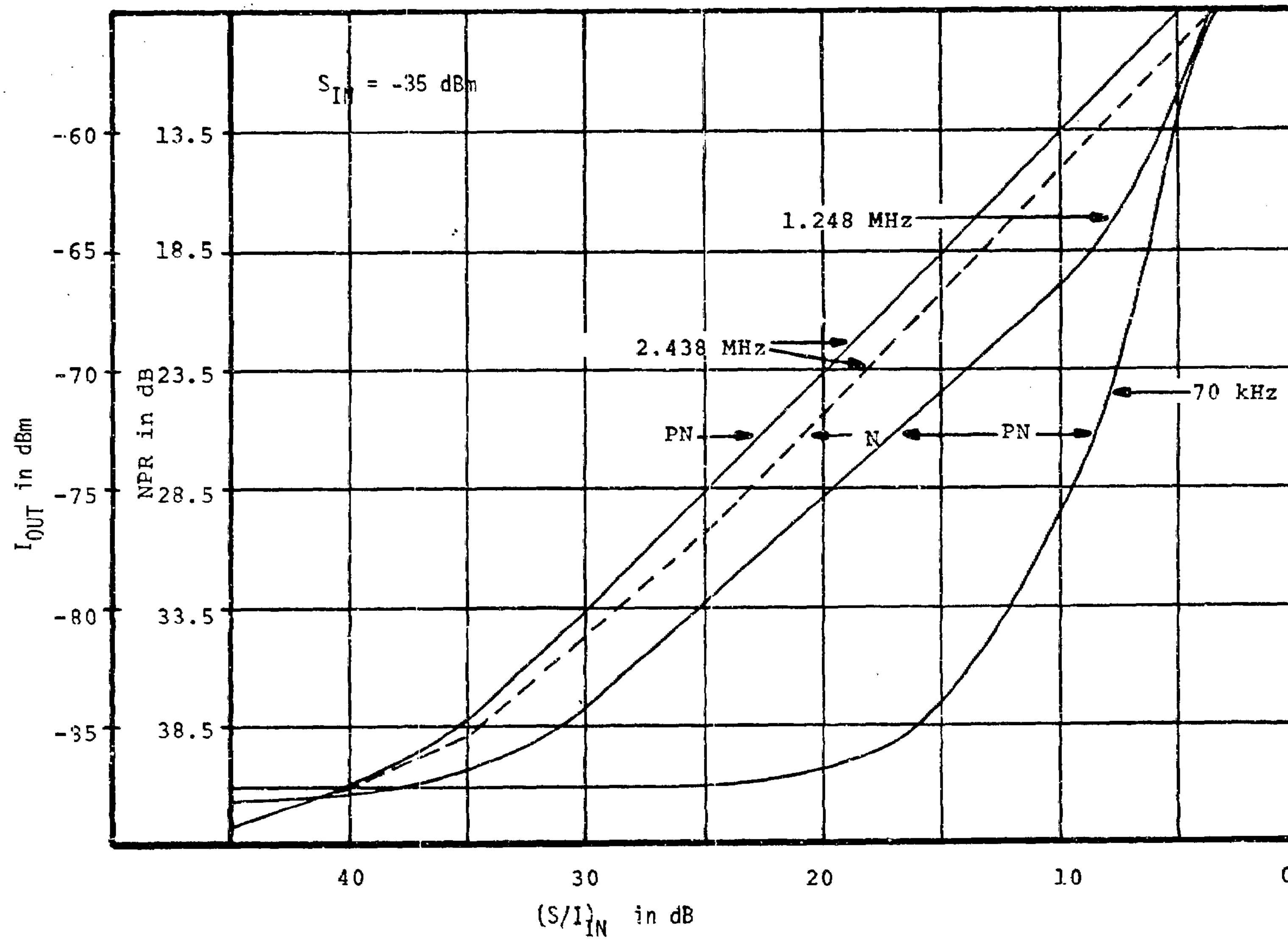


Figure 15 Slot Noise Power Versus PN and N Interference

$$PG_{PN} = 25.5 - 22 + 16 - .9 \text{ dB} = 18.6 \text{ dB} \qquad (5\text{-}4)$$

$$PG_{N} = 27.1 - 22 + 16 - .9 \text{ dB} = 20.2 \text{ dB} \qquad (5\text{-}5)$$

$$PG_{CW} = 25.5 - 22 + 16 - .9 \text{ dB} = 18.6 \text{ dB} \qquad (5\text{-}6)$$

These values along with the theoretical noise PG are compared with the corresponding theoretical values in Table 1. The ideal noise interference PG should be 3 dB greater than the quieting PG since the bandwidth of the PN signal is approximately 40 MHz and the bandwidth of the TVA receiver limited IF is 22 MHz. Therefore, we have that:

$$PG_N = PG_{NQ} + 10 \log (40 \text{ MHz}/22 \text{ MHz})$$
$$= PG_{NQ} + 3 \text{ dB}$$

There is a theoretical 1.5 dB difference between the measured PN interference and the noise interference for the same bandwidth (40 MHz). This is due to the $(\sin x/x)^2$ roll off of the PN spectrum versus the flat gaussian noise spectrum. That is, the PN noise component at 2.438 MHz is effectively higher than the flat noise component at this frequency because the total power of the $(\sin x/x)^2$ is averaged over the 40 MHz bandwidth. This normalization effectively raises the central portion of the spectrum and lowers the tails of the $(\sin x/x)^2$ roll off. This is shown in Figure 16.

The on tune CW processing gain is given by Equation 5-7:[16]

$$PG_{CW} = \sqrt{2\pi} \; \frac{\delta f^2 f_s}{b f^2_m} \; \exp(f^2_m/2f^2_s) \qquad (5\text{-}7)$$

$$= \sqrt{2\pi} \; \frac{(200)^2(871)}{(3.2)(2438)^2} \; \exp \frac{(2438)^2}{2(871)^2}$$

$$= 231$$

$$PG_{CW}\big|_{dB} = 23.6 \text{ dB}$$

TABLE 1

COMPARISON OF MEASURED AND THEORETICAL PROCESSING GAIN

TYPE OF PROCESSING GAIN	MEASURED PROCESSING GAIN IN DB	THEORETICAL PROCESSING GAIN IN DB
Quieting Slot Noise (f^2)	17.1	16.7
PN Interference	18.6	18.2
Noise Interference	20.2	19.7
CW Interference	18.6	23.6

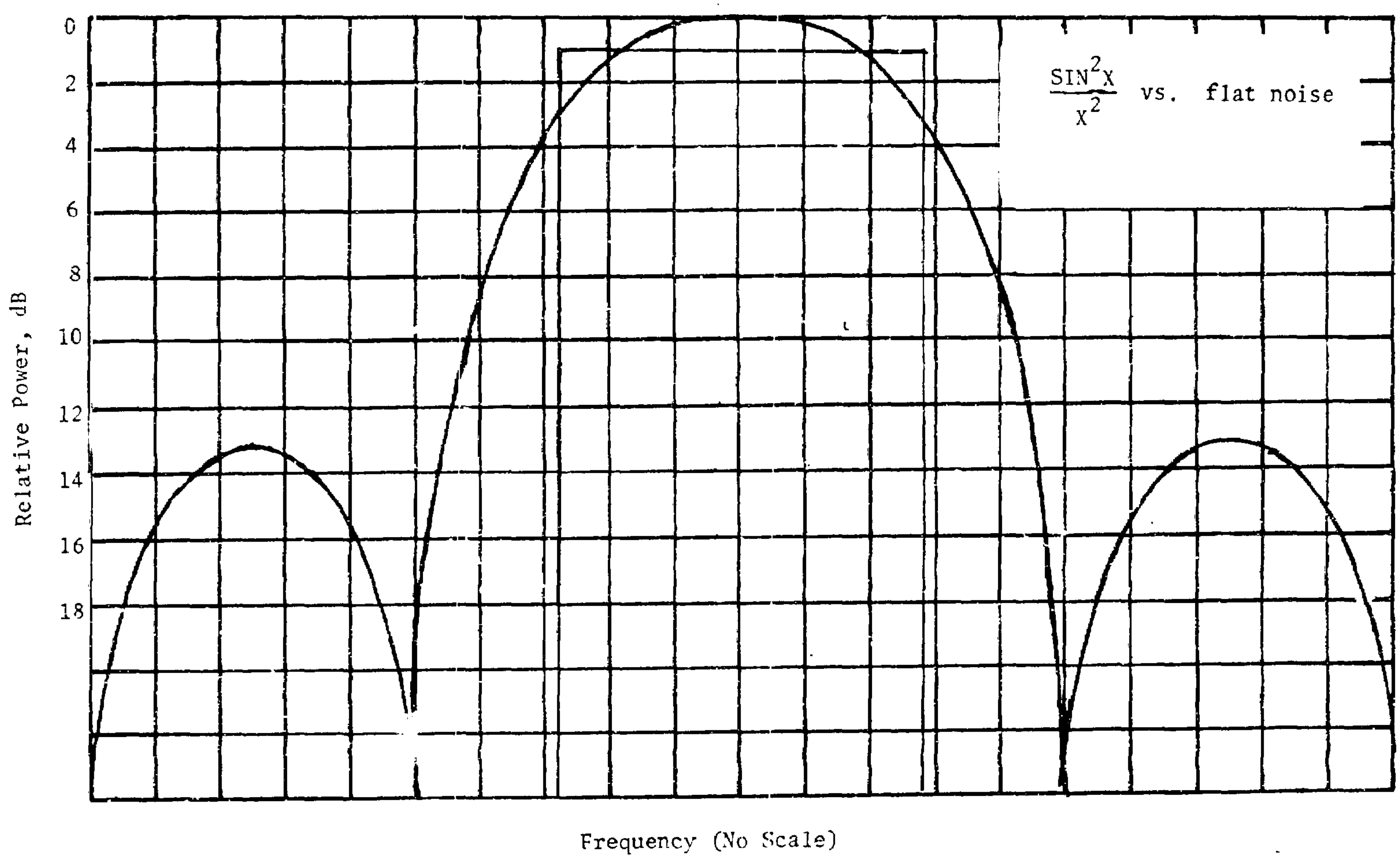


Figure 16 Difference between PN and flat noise.

The difference between this value and the measured value is 5.0 dB. The greater difference between the theoretical and measured PG value for the CW case compared to the PN and N case is due to the fact that the equation does not apply to low deviation ratios.

The slot noise measurements were run over an interference power range from below system noise up to an $(S/I)_{IN}$ of 0 dB.

The processing gain remained constant for $(S/I)_{IN}$ up to 2 dB for PN interference, Figure 15. This is due to the constant amplitude of the PN signal as opposed to the amplitude variations of gaussian noise.

Thus, the non-linearities and degradation in PG which occur when the classical FM improvement threshold of 10 dB $(S/I)_{IN}$ is broached, do not occur and the system remains linear until the interference begins to capture the receiver.

Off-Tuned Effects - A test was conducted in which the slot noise interference was monitored as a -46 dBm PN signal was injected on-tune and moved in 10 MHz steps out to 50 MHz off-tuned. This data is presented in Figure 17. A computer calculation of the theoretical OFR is in close agreement with this data.

FLIGHT TESTS

General - The objectives of the flight tests were to determine the amount of interference which could potentially be coupled into the TVA system from the airborne SHF SATCOM transmitter. Three basic tests were conducted which (a) located the area of maximum power transfer, (b) determined the exact power level of the SHF SATCOM carrier in the TVA receiver, and (c) determined the amount of interference coupled into the baseband channels.

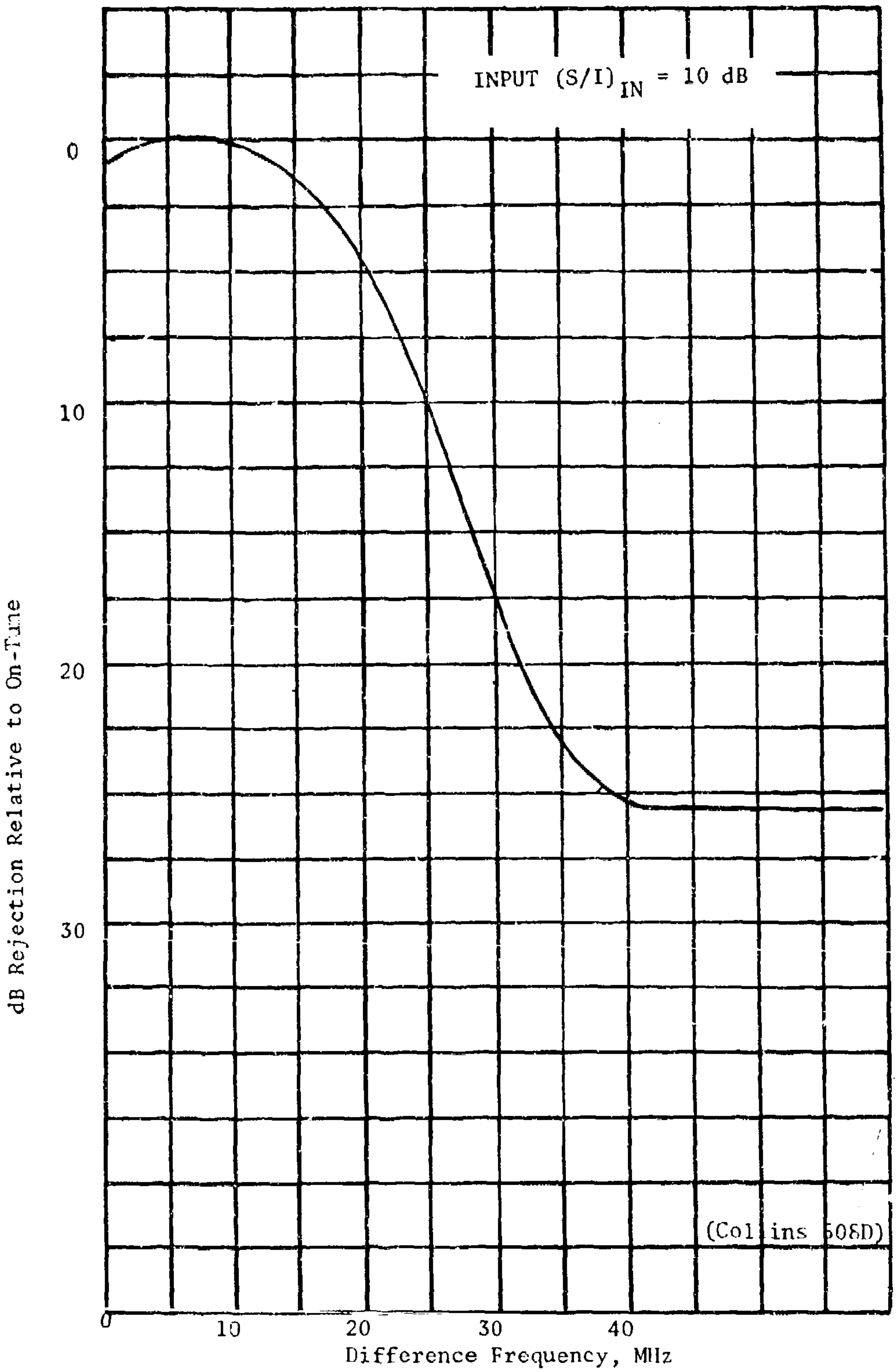


FIGURE 17 OFF-FREQUENCY REJECTION TO PN INTERFERENCE

The results of these tests were then used in conjunction with the ground test results and theoretical analyses to determine the degree of degradation to the system.

In the first two tests, the airborne SHF SATCOM transmitter was not modulated and was tuned to the center frequency of the McEwen site (Site 2, 8255 MHz). The desired signal from the Johnsonville site (Site 1) was turned off. The AGC voltage, baseband quieting and the received IF power (prior to limiting) were monitored and recorded. The test arrangement for these runs is shown in Figure 18.

For the third test, the aircraft was flown in regions of maximum power transfer. The airborne SHF SATCOM system was placed in various configurations and the interference noise power in the slotted channel of a fully loaded baseband transmitted from Johnsville was recorded. AGC and combiner squelch voltage (CCV) were also recorded. The test configuration for these runs is shown in Figure 19.

The details of the flight configuration and the conduct of the test are presented in Reference 7 and will not be elaborated upon here.

TEST RESULTS

Overflight - Four flights were conducted directly along the main beam azimuth and over the McEwen site to identify the areas of maximum power coupling. The main beam and first sidelobe regions were identified and it was confirmed that these areas did produce the highest interference powers. These areas were located at 122 and 175 nm from the site, Figure 20. No significant antenna lobes were encountered until the aircraft was greater than 100 miles from the site. This test was run with the airborne SHF SATCOM antenna at an elevation angle of -2°. One overflight was

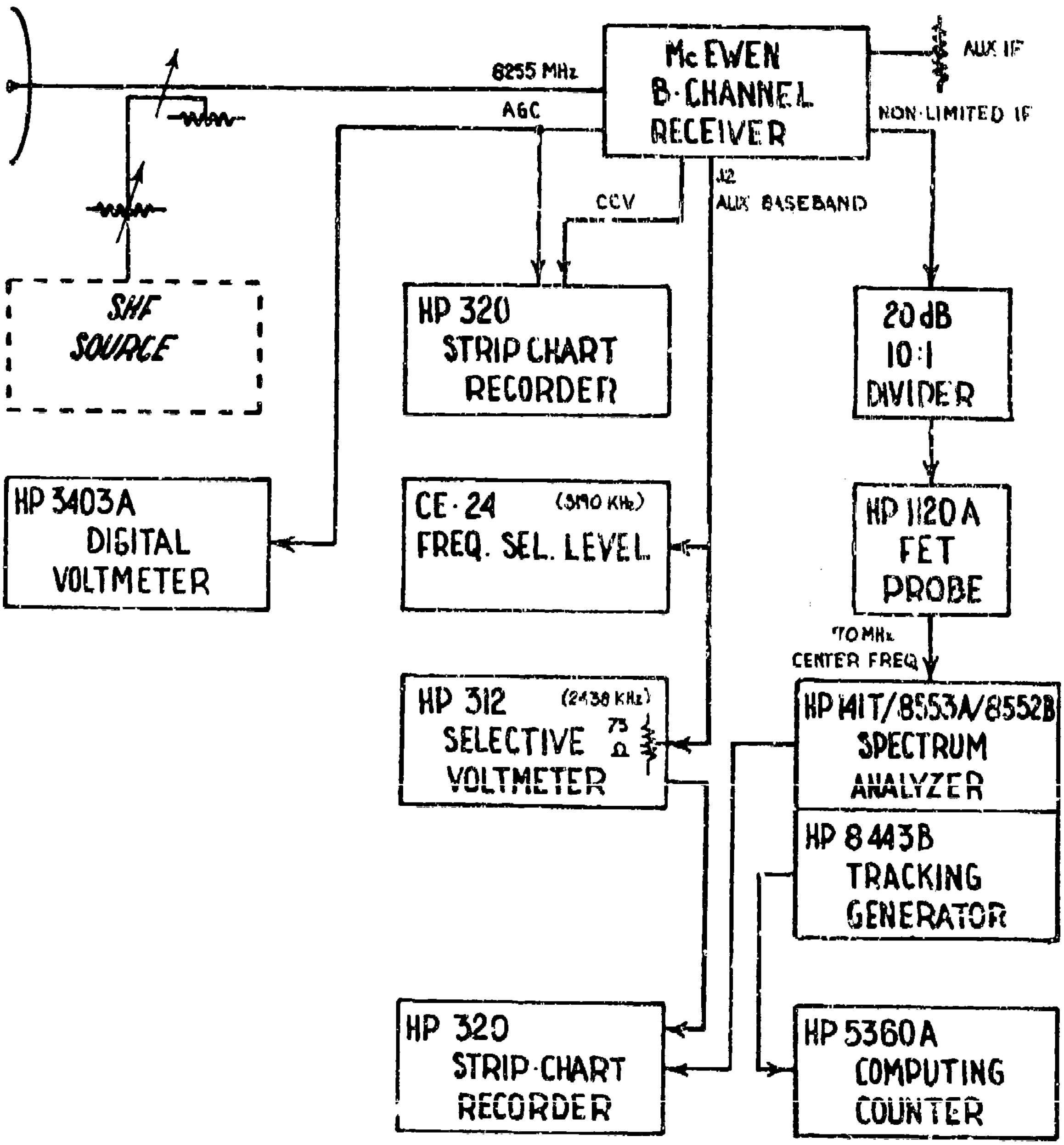


Figure 18 TVA CW Coupling Measurements Test Setup

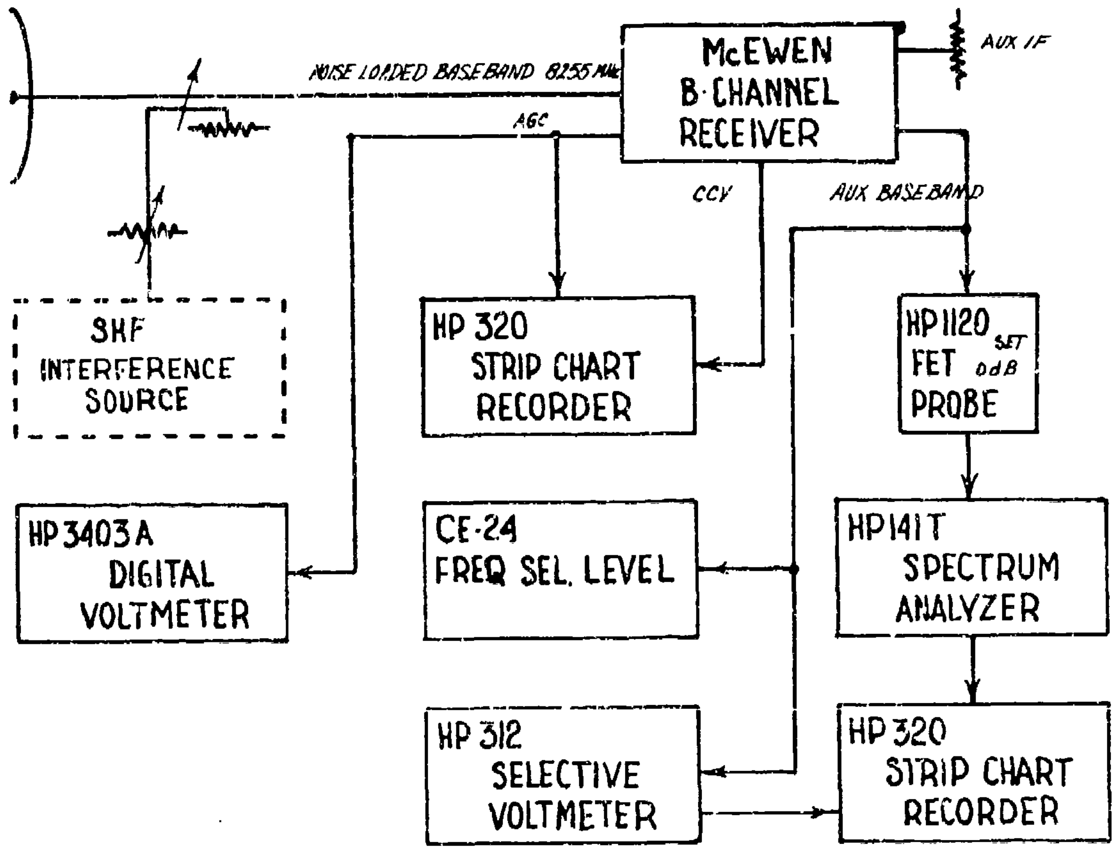


FIGURE 19. TVA GRO' .D TEST SETUP

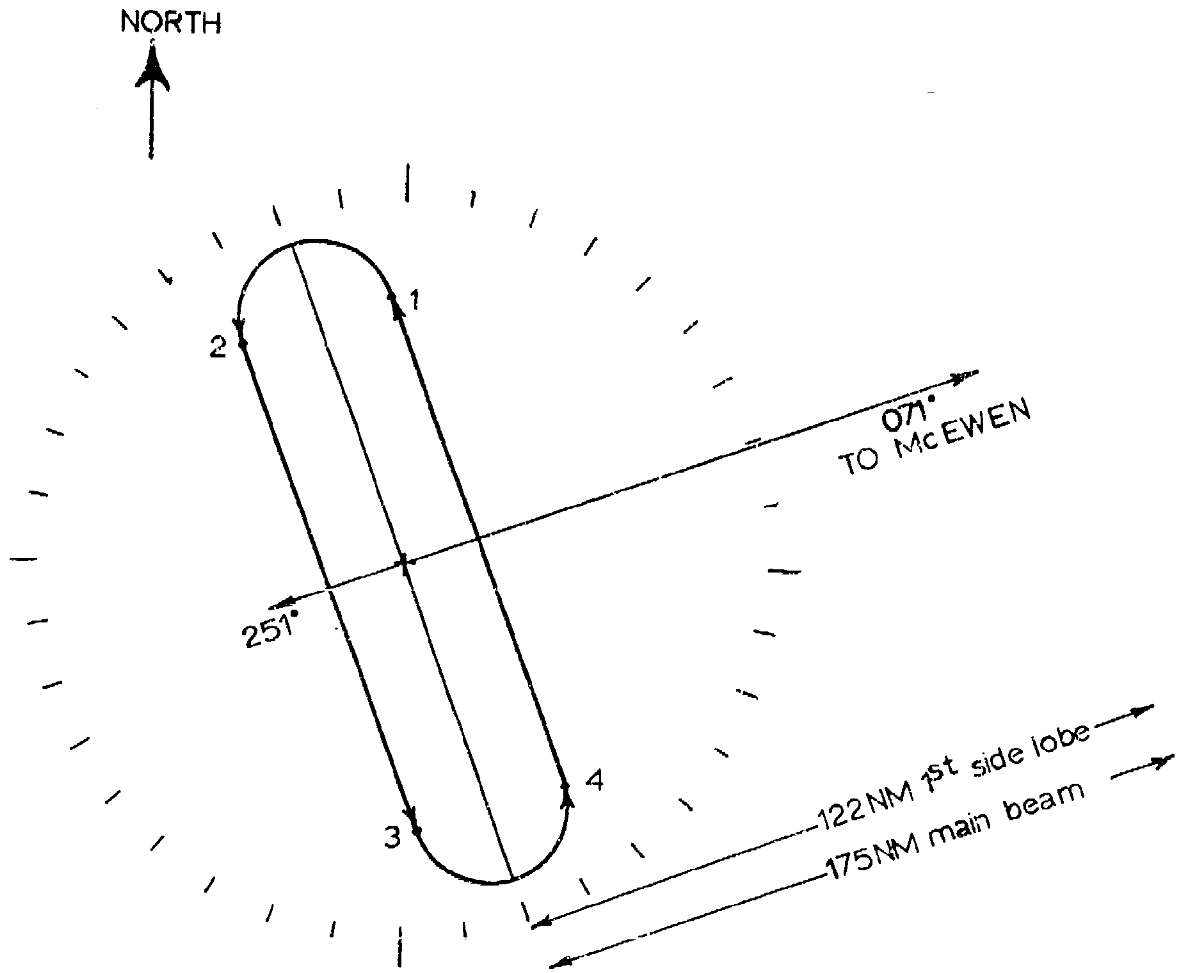


Figure 20 McEwen Flight Orbit

conducted with the aircraft antenna at a typical operating elevation angle of +10° and no signal was detected closer than 100 miles from the site.

Power Coupling-Main Beam - Ten flights were flown through the main beam with the airborne SHF SATCOM transmitter radiating 5 kW at relative azimuth angles of 0°, 45° and 135° to the direction of McEwen. The antenna was aimed at +10° and +20° elevation. The absolute peak power received for the various pointing arrangements is given in Table 2 and a plot of the worst case signal received as the aircraft traversed the beam is given in Figure 21.

TABLE 2

MAXIMUM POWER COUPLING

	Relative Azimuth to McEwen		
	0°	45°	135°
Received power at 10° elevation	-53 dBm	-53 dBm	-74 dBm
Received power at 20° elevation		-56 dBm	-72 dBm

Theoretical Power Coupling - In the flight test at McEwen, Tennessee, the flights were configured so that the aircraft crossed the main beam of the 8 foot microwave antenna at a distance of 165-180 nm (Figure 20). The aircraft antenna beam was at an elevation angle of 10° and pointed toward the McEwen site. The airborne SHF SATCOM transmitter was radiating 5 kW of CW power. The theoretical received power at the system measurement

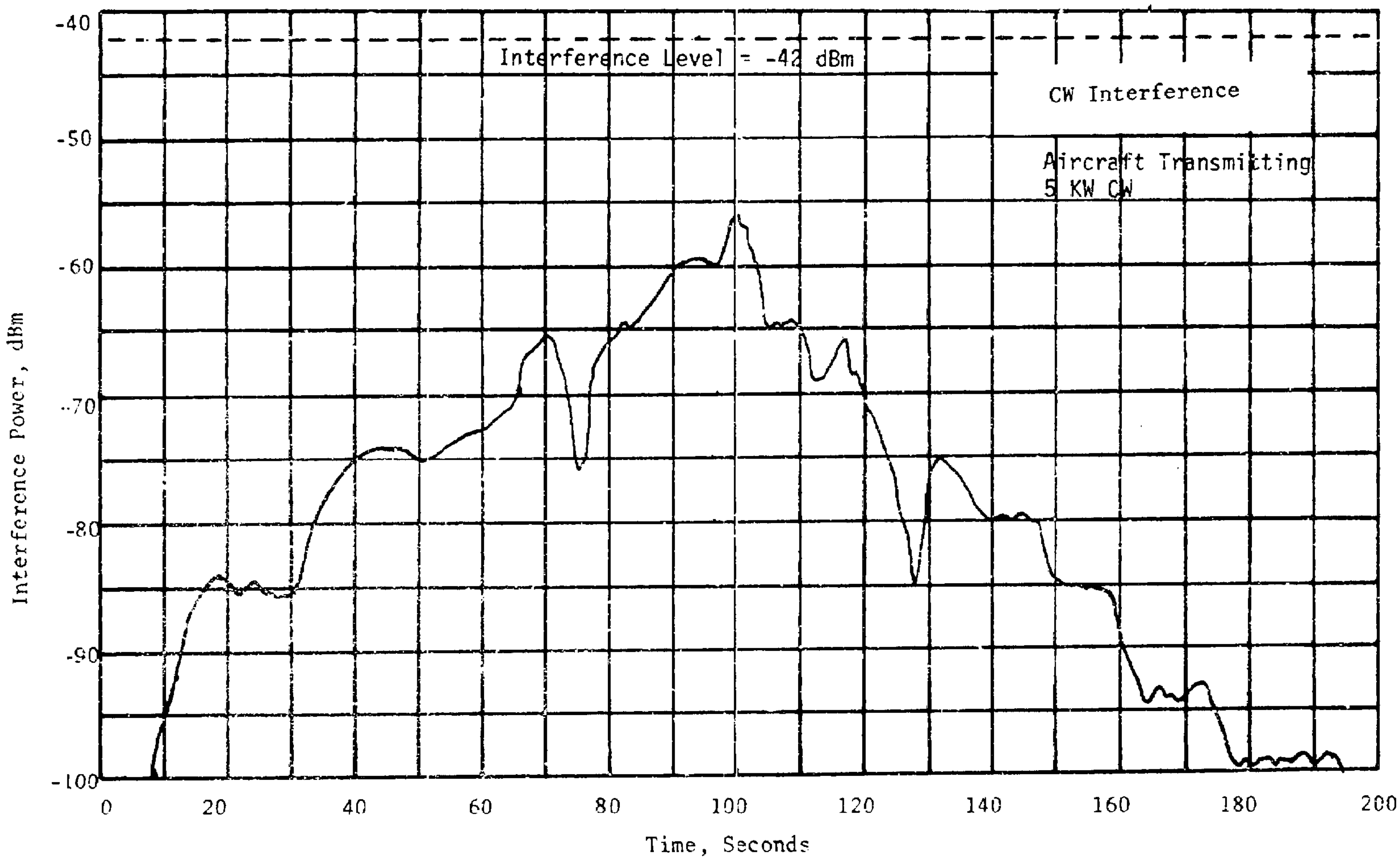


Figure 21 CW interference power at receiver front end.

point, i.e., bottom of antenna waveguide run, is given as follows (Equation 3-7):

$$I_{IN} = I_T + G_T - L_R - L_{FS} - L_A + G_R - L_{WG} \tag{5-8}$$

$$+ 67 - 1 - 0 - 160 - 2 + 44 - 2.9 = -54.9 \text{ dBm}$$

The actual measured power level during the flight was -53 dBm maximum.

Power Coupling Sidelobe - A full set of data was taken in the region of the first vertical sidelobe. Although the location of this lobe is much closer to the site (122 miles versus 175 miles) the beam gain is sufficiently reduced to cause the coupled power to be considerably less than in the main beam. The maximum received power during these flights was -65 dBm as opposed to 53 dB for the main beam flights.

Interference Flight Tests - Of the 28 flights through the main beam 14 were run at 5 kW with PN modulation, 10 were run at 5 kW with FH modulation and 4 at 100 watts PN. Table 3 presents the worst case slot noise measurement for the various flight test configurations. Each configuration was run at least twice. All other measurements in each category were from 2 to 6 dB below that which is shown.

Using the 2.438 MHz slot noise versus PN interference curve (Figure 15) generated during the ground measurements the input interference power can be determined. The worst case measured slot noise level of -73 dBm was generated by an input PN signal power of -58 dBm. There is no readily available explanation of exactly why this peak received signal is 5 dB below the peak CW signal received during the power coupling flight tests. It will simply be noted that out of the total of 38 flights the peak

TABLE 3

SUMMARY OF FLIGHT TEST SLOT NOISE

POWER	MODULATION	ANTENNA ORIENTATION	NUMBER OF MEASUREMENTS	PEAK SLOT NOISE WHILE IN MAIN BEAM
5 kW	PN	TOWARD McEwen	6	-74 dBm (-59 dBm)*
		AWAY	8	-84 dBm (-69 dBm)*
	FH	TOWARD	4	-73 dBm (-58 dBm)*
		AWAY	6	-80 dBm (-65 dBm)*
100 W	PN	TOWARD	2	-85 dBm (-70 dBm)*
		AWAY	2	-87.5 dBm (<-70 dBm)*

System noise in slot with no interference -89.5 dBm.

*Input interference PN signal level

received power of -53 dBm was reached only three times. All other received interference power levels were at least 5 dB below this level.

Figure 22 is a plot of the typical frequency hopping (FH) and PN interference versus time as the aircraft flew through the beam. In order to determine the time distribution of the interference power above the microwave system sensitivity level, the slot quieting measurement shown in Figure 21 will be used since an unmodulated FM system has a lower residual slot noise than a noise-loaded FM system. Due to intermodulation of the noise-loaded system the residual slot noise rises about 12 dB above that of the unmodulated system, thus restricting the lower limit to which interference may be sensed. When the system was noise loaded the interference rose only 17 dB above the residual slot noise (Figure 22).

In order to insure that the structure of the peak of the quieting curve was representative of the actual pattern, the curves of all the interference and quieting measurements were plotted on an absolute power basis. The curves were also made symmetrical about their peak value. It was found that the quieting curve of Figure 21, when made symmetrical about its peak, was the worst case and encompassed the values of all other measurements. This curve is plotted in Figure 23.

During the interference tests, two information modulation rates were used (75 bps and 4.8 kbps). No noticeable difference was observed for the PN interference. However, for the FH modulation there was an observable difference in the critical control voltage. This circuit controls the switching of the combiner in the diversity system. It was noted that at low data rates, this circuit was approximately 6 dB more sensitive to FH than PN noise. In both cases, the system squelched at a CCV of 2V which is equivalent to a slot noise of -58 dBm for PN. That equates to a $(S/I)_{OUT}$

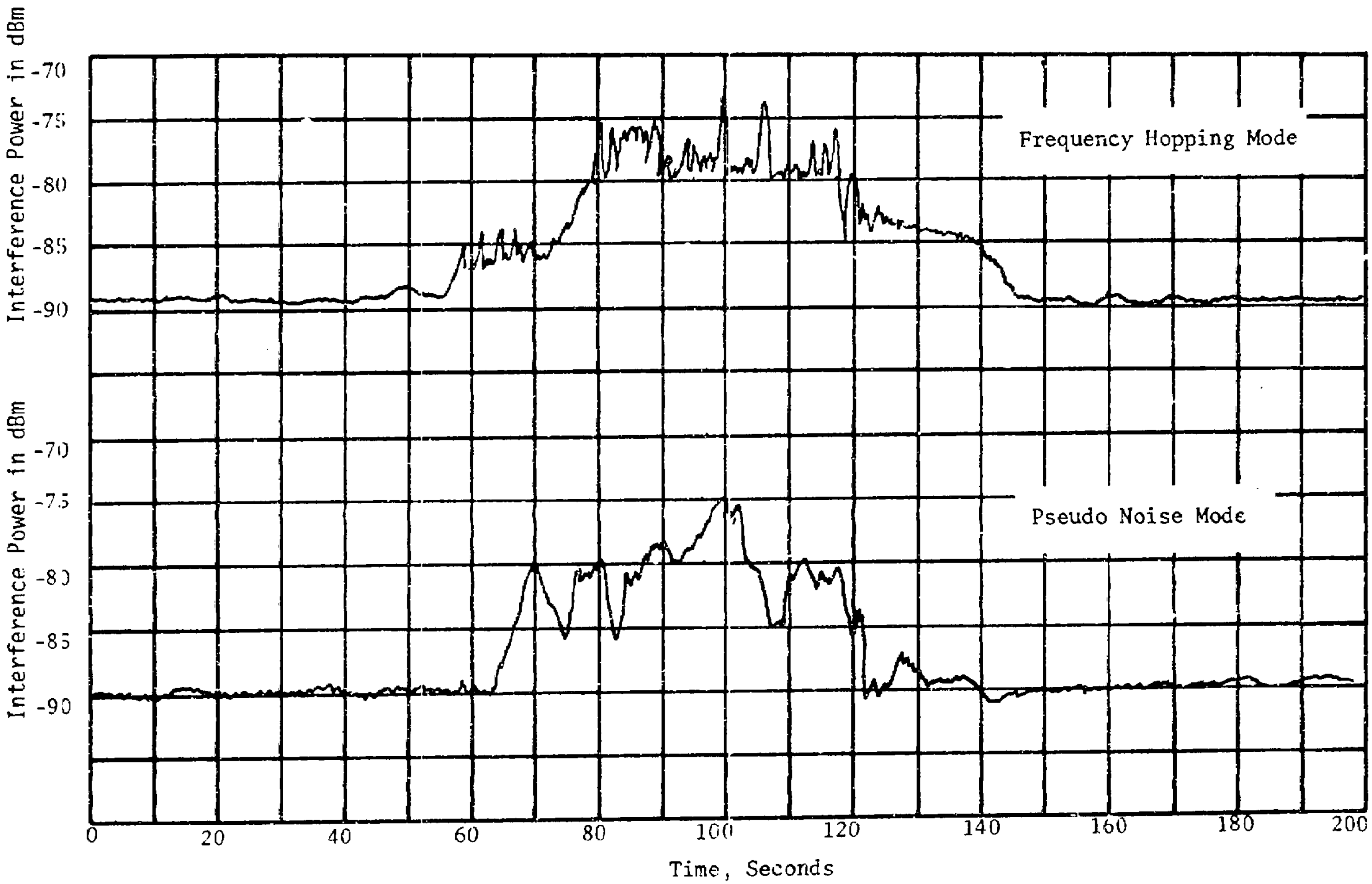


Figure 22 Interference power in base band channel (flight test).

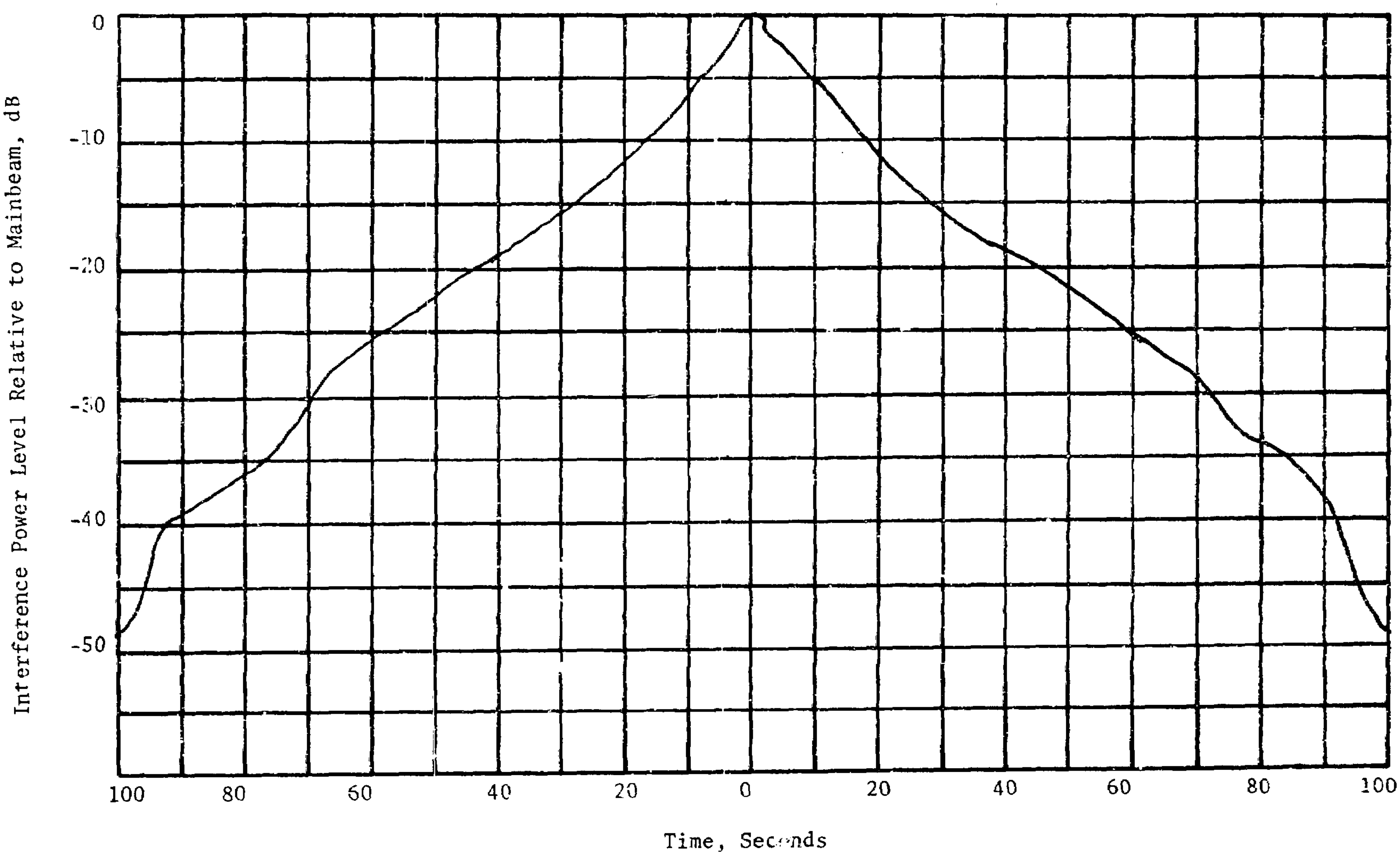


Figure 23 Worst case time distribution of interference.

of 25 dB and an 8 dB $(S/I)_{IN}$. The frequency hopping mode of interference produced a lower CCV for a given level of slot noise, thus causing the diversity system to function at a 6 dB lower slot noise.

SUMMARY OF TESTS

Ground Tests

1. The system vulnerability to noise and PN modulation is approximately the same.

2. Theoretical predictions of off tuned coupling were verified.

Flight Tests

1. The worst case measured power coupled into the microwave receiver agrees closely with the theoretical computation.

2. Outside of the main beam and near sidelobe regions the airborne SHF SATCOM terminal signal is virtually undetectable and does not degrade normal signal-to-noise ratios in baseband channel.

3. In the near sidelobe region, the interference power level never exceeded -65 dBm or a slot noise of -80 dBm.

4. Time during which the interference power exceeds a decibel level relative to the peak is given below:

Decibels Below Peak	(Seconds) Time	Decibels Below Peak	(Seconds) Time
0	2	-20	90
-5	10	-30	140
-10	30	-40	190
-15	60	Noise	200

5. Operating the airborne SHF SATCOM transmitter at 100W produced a signal which was just detectable (4 dB above system noise for 5 seconds)

while the aircraft traversed the main beam. At all other times the signal was undetectable.

6. If the aircraft antenna is aimed 90° or more from the ground site the monitored interference power level is 10 dB less than the worst case.

INTERFERENCE ANALYSIS

General - The basic approach to the interference analysis is to define a baseline system and to determine the worst case impact of the airborne SHF SATCOM system upon its operation.

This baseline system will then be used on a comparative basis in evaluating the impact of the airborne SHF SATCOM system upon the operating systems of the TVA and BPA networks. The McEwen site was originally chosen for testing because it appears to typify a large segment of the operational environment. The test program verified its operating characteristics and the predicted response of the system characteristics. These systems will be used as the baseline for the analysis.

The worst case theoretical and measured data was used to determine the amount and time distribution of the interference to McEwen's normal operation.

It should be emphasized that these studies used assumptions which biased the analyses towards an interference situation. When marginal situations were encountered, some of the assumptions had to be reexamined to determine their applicability to the individual case.

The McEwen system was first analyzed as a non-diversity system to determine the relationship of airborne SHF SATCOM interference signals to the

system performance requirements. This information was then used to determine the probability that the system would fall below a specified performance level while the interference signals were present. These data were subsequently used to evaluate the effects of total frequency and space diversity.

Nondiversity System - The worst case interference will result from radiating 10 kW from the airborne SHF SATCOM transmitter. The worst case received interference power measured during the test was -53 dBm while radiating 5 kW. Therefore, the highest received interference power in a full power configuration will be taken as -50 dBm $(I)_{IN}$. The desired signal during the tests was -35 dBm $(S)_{IN}$ and the measured processing gain is 18.6 dB (PG). These values provide input and output signal-to-noise ratios according to:

$$(S/I)_{IN} = S_{IN} - I_{IN} \tag{5-9}$$

$$(S/I)_{IN} = -35 - (-50) = 15 \text{ dB}$$

$$(S/I)_{OUT} = (S/I)_{IN} + PG_{PN} \tag{5-10}$$

$$(S/I)_{OUT} = 15 + 18.6 = 33.6 \text{ dB}$$

As specified in Reference 1, the minimum acceptable $(S/N)_{OUT}$ or $(S/I)_{OUT}$ is 25 dB. If the interference signal is equated to noise, the maximum interference level is 8.6 dB below the threshold, i.e., $(S/I)_{IN}$ = 8 dB.

Interference at the threshold will produce an output signal-to-noise of 25 dB. It is not possible to discuss here the exact effects of the interference on the information in the multiplex channel since the type of information varies widely from system to system. However, the 25 dB

$(S/I)_{OUT}$ is based upon white noise which shows a rapid decay in $(S/I)_{OUT}$ for $(S/I)_{IN}$ of less than 10 dB. In the measurement, it was demonstrated that the system remained linear for very small input signal-to-interference ratios. For an $(S/I)_{IN}$ of 2 dB, the processing gain still provided a 17 dB $(S/I)_{OUT}$. Consideration should be given to this fact when evaluating the impact of airborne SHF SATCOM terminal operation on an individual system.

Probability of Interference - The impact of the airborne SHF SATCOM terminal interfering signal upon the operation of the microwave systems was evaluated by examining the worst case probability of interference. As previously computed, the maximum received interference level is 7 dB below the threshold, i.e., the interference level which would produce a 25 dB $(S/N)_{OUT}$. Therefore, in order for interference to occur, the desired signal must be faded. The normal system outage probabilities versus fade margin and path length are plotted in Figure 24. The values are taken from References 17 and 16 and are for temperate inland conditions over water. As the figure shows, a 20 mile path set up with a 40 dB fade margin will have a probability of outage of 2×10^{-5}. The use of these outage values for interference analysis was as follows: As the aircraft flies through the beam of the microwave system the instantaneous fade margin is reduced by the interference to noise threshold ratio.

Examination of the interference power levels given in Figure 23 will clarify this. The peak signal at 0 dB on scale will produce a 7 dB fade margin for two seconds. This means that if the signal faded 7 dB the system would experience an outage for two seconds. Likewise, a 17 dB fade would produce an outage of 32 seconds, etc., on through the range of interference

power levels. The probabilities of outage associated with the various fade margins is taken from Figure 24 and presented in Table 4 for four microwave system path lengths and airborne SHF SATCOM transmitter powers of 10 and 1 kW.

The outage probability values given in Table 4 are the fraction of time that the signal will fade to the specified depth or greater. Thus, considering the 20 mile path, which is slightly greater than the baseline system, the value of .04 for the 7 dB fade means that 4% of the time the signal will be 7 dB or more below the median and 96% of the time the fade will be less than 7 dB down, thus, no interference. The value in the second line of .013 for an 11 dB fade means that the signal will fade 11 dB or more 1.3% of the time. This means that the signal fades somewhere between 7 and 11 dB 2.7% of the time (4% - 1.3%). The time duration of the interference during such fades is between 2 and 10 seconds. Likewise, the third line in the table indicates the signal fades 14 dB or more 0.6% of the time. Therefore, the signal will fade between 11 and 14 dB for 0.7% of the time (1.3% - 0.6%), with an interference durati[illegible] seconds.

The new percentage figures indicate the percent of the [illegible] number of flights through the microwave beam which will cause an interference outage of a specified duration.

If we assume the aircraft flies through the microwave b[illegible]m once a day, the total outage time over a year can be computed and [illegible] s[illegible] n Table 5. This computation is for a 20 mile microwave link with the airborne SHF SATCOM terminal radiating 10 kW. As can be seen, the total outage

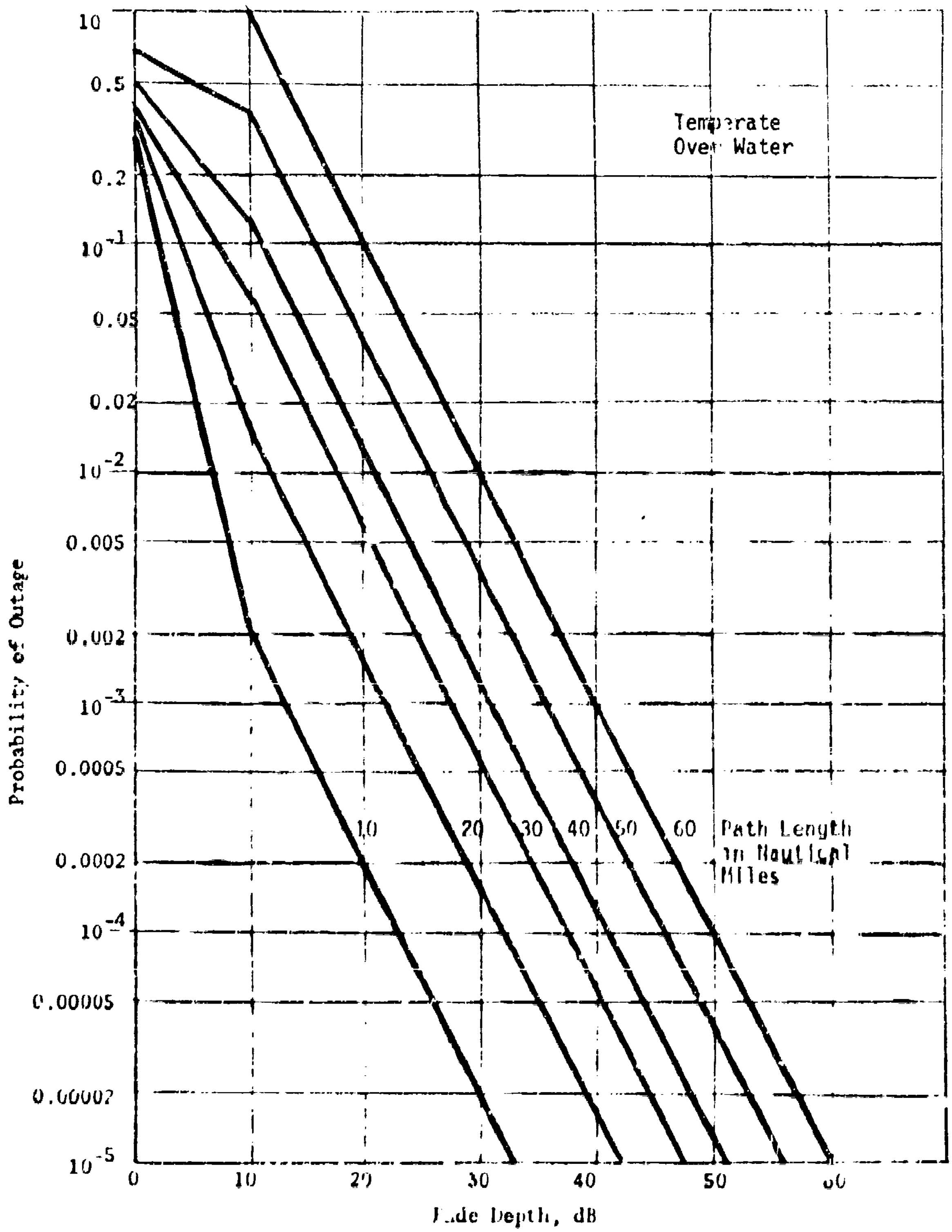


Figure 24 Outage probability.

TABLE 4

PROBABILITY OF OUTAGE

SHF POWER 10kW/1kW INT FADE MARGIN dB		TIME SECONDS	PROBABILITY OF OUTAGE FOR 10kW (TOP) AND 1kW (BOTTOM) PATH LENGTH 10 mi	20 mi	30 mi	40 mi
7		2	.01	.04	.1	.2
	17		.0004	.003	.012	.025
17		10	.0015	.013	.05	.1
	21		.00015	.0012	.005	.01
14		20	.0008	.006	.023	.05
	24		*	*	*	*
19		40	.00025	.002	.007	.015
	29		*	*	*	*
23		60	.0001	.0008	.003	.006
	33		*	*	*	*
32		120	.000013	.0001	.00035	.0008
	42		*	*	*	*
42		150	.0000013	.00001	.000035	.00008
	52		-	-	-	-
46		180	.0000005	.000004	.000013	.000032
	-			-	-	-
50		210	.0000002	.0000016	.000005	.000012
	-			-	-	-

*Decrease upper number by factor of 10.

time is extremely small: 3 minutes per year, or an outage probability of 6×10^{-6}. The same computation was accomplished for the 40 mile path and the results were 1,212.85 seconds or 20.21 minutes of outage per year for an outage probability of 4×10^{-5}.

The above computations considered the aircraft flying at 90° to the microwave beam. The total time during which the signal was detectable was about 200 seconds for the worst case. This equated to about 20 miles in distance. The aircraft signal was detectable in as close as 100 miles and as far out as 210 miles. Therefore, if the aircraft flew down the beam the total time the signal would be detectable would be increased by a factor of 5. The outage probabilities would then increase to 3×10^{-5} and 2×10^{-4}, respectively, for the 20 and 40 mile microwave links.

DIVERSITY

Frequency Diversity - The reliability of a single circuit is increased through the use of frequency diversity[18] by a factor between 10 and 100. Thus, in a frequency diversity system the impact of reducing the reliability of one side of a frequency diversity link by a factor of 10^3 or 10^4 will reduce the overall reliability by no more than the improvement factor of the diversity system itself.

In the interference analysis, the governing factor for assessing the impact of the system should be measured in terms of the diversity improvement factor rather than the individual hop fade margins.

Previous analyses[14,20] had concluded that the interference power would exceed the median desired signal level whenever the airborne SHF SATCOM

TABLE 5

OUTAGE PER YEAR FOR ONE FLIGHT PER DAY AT 10 kW (PERPENDICULAR TO LINK)

FADE EXCEEDED	DURATION EXCEEDED	PROBABILITY	DURATION FROM-TO	AVERAGE DURATION	% TIME FADE EXISTS	NO. OF FLIGHTS	TOTAL OUTAGE
7 dB	2 sec	.04					
			2 - 10	6 sec	2.7%	9.85	59 sec
11 dB	10 sec	.013					
			10 - 20	15 sec	0.7%	2.55	38 sec
14 dB	20 sec	.006					
			20 - 40	30 sec	0.4%	1.4	42 sec
19 dB	40 sec	.002					
			40 - 60	50 sec	0.12%	.44	22 sec
23 dB	60 sec	.0008					
			60 - 90	75 sec	0.05%	.18	13.5 sec
27 dB	90 sec	.0003					
			90 - 120	105 sec	0.02%	.073	7.7 sec
32 dB	120 sec	.0001					
			120 - 150	135 sec	0.019%	.069	9.3 sec
42 dB	150 sec	.00001					
			150 - 180	165 sec	0.0006%	.0022	.3 sec
46 dB	180 sec	.000004					
						Total Outage	191.8 sec
						Per Year	3.2 min
						% Time	6×10^{-6}

terminal passed through the main beam. Thus, there was a problem that during maintenance routines there was a probability of one that an outage would occur if the aircraft happened into the main beam while one side of the link was down. As was seen in the discussion of probability, with the parameter values available as a result of the measurement program, the anticipated probability of an outage on a single side of a hop is less than one for all cases examined.

It is, therefore, concluded that there is no significant impact on frequency diversity circuits by the airborne SHF SATCOM terminal even operating at 10 kW and with minimum angular separations between the main beams.

Space Diversity - In the analyses conducted to date it has been assumed that space diversity would offer no protection against airborne SHF SATCOM terminal interference. Considering the nature of the diversity system and the anticipated dynamics of the airborne SHF SATCOM terminal signal strength at the microwave receiver, it appears plausible that some improvement could be obtained. Examination of the data acquired during the testing of all systems indicates severe multipath fading exists in the interfering received signal. During the tests at the FAA, three receivers were utilized in an attempt to correlate power density and the signal received by the microwave antenna in hopes of determining the on and off axis gain of the microwave system. These signals (three) were recorded on the same recorder with a common time base. These signals were extremely difficult to correlate. Instantaneous differences of 6 to 10 dB were noted consistently between any two of the receivers. The cyclic nature of the received signal is due to convolving the two multilobed antenna patterns, multipath, path medium fading and aircraft motion.

These recordings are not unlike those taken on space diversity systems during actual fades. Both signals fade on the average nearly the same amount, but on a short term basis they fade out of phase and one signal is available most of the time above the squelch level.

A similar effect appears to be occurring between the separated receivers in the FAA test. Insufficient data was obtained and the test was not configured nor intended to provide such data, to form any firm conclusion. However, some improvement should be realized.

The computed signal strengths and outage probabilities for the space diversity links will be based upon the assumption that there will be no diversity improvement. However, these observations should be borne in mind when evaluating margin situations. They are indicative that the worse case is under consideration.

TVA SYSTEM CONSIDERATIONS

General - The TVA system was examined in detail in order to determine the extent to which the individual systems in an overall network will vary from the baseline system typified by the McEwen system. Of particular interest will be changes in antenna configuration, reduced fade margins, and the use of space diversity and non-diversity systems. The Bonneville Power Administration system in northwestern U.S. was examined for the same variations. This system is quite similar to that of the TVA's.

System Description - The TVA system consists of a series of interconnected multiple hop links operating in the 7.250 to 8.4 GHz. These links carry multichannel, analog data and control signals which allow for the control and integration of the various power sources and transmission facilities throughout the TVA area.

In the 7.9 to 8.4 GHz portion of the band, the system uses Collins 508 A/B RF and D RF, Collins 518 and Motorola MR-300. All these systems are designed and loaded to CCIR specifications for 600 channels. The majority of the systems operate with frequency diversity. One major link and its spurs (NASH LONS) uses space diversity and three spurs use no diversity.

Virtually all types of antenna configurations are used (tower mounted parabolas, vertical and offset periscopes and midpath reflectors). Table 6 lists the systems operating in the 7.9 to 8.4 GHz band.

Effect of Increased Antenna Gain - A system operating at the baseline fade margin with an antenna other than an 8 foot dish or 44 dBi gain will receive an interference power proportionate to the difference in the antenna gains. Examination of the TVA systems listed in Table 6 shows 19 systems using 10 foot antennas. The antenna gain is 2 dB greater than an 8 foot antenna and 3 dB greater when using a properly aligned 10 x 15 foot reflector. Since the baseline system had a 7 dB margin, the impact of the 2 to 3 dB degradation in interference to threshold ratio will be minimal.

Twelve of these systems operate with space diversity. Six of these systems have fade margins which are sufficiently larger than the baseline system to offset the 2 and 3 dB increase in antenna gain. Six sites (three links) will experience an interference to threshold approximately 2 dB below the baseline value. These are:

Russell Hill to Summer Shade

Ellis Mountain to Sharp Ridge

Signal Mountain to Sequoyah

This will increase the probability of interference by a factor of about 1.5.

TABLE 6

TENNESSEE VALLEY AUTHORITY FIXED MICROWAVE LINKS IN THE 7.9 - 8.4 GHz FREQUENCY RANGE

PATH	DISTANCE (MILES)	EQUIPMENT	ANTENNAS				DIVERSITY	FREQUENCY (MHz)	FADE MARGIN (dB)
			PARABOLA (FEET)	REFLECTOR (FEET)	GAIN (dBi)	DW (°)			
Wilson- Gallatin	8.4	MR300 (Motorola)	10 10	------- 10 x 15	46 47	0.9 0.8	Hot Standby	8345 8185	51.5
Russell Hill- Summer Shade	32.8	MR300	10 10	------- 10 x 15	45 47	0.9 0.8	Space	8185 8345	40.6
Sharp Ridge- Alcoa	16.8	MR300	10 10	------- 10 x 15	45 46	0.9 0.8	Space	8305 8125	----
Nashville- Wilson	16.0	MR300	6	10 x 15	42	0.8	Space	8035	42.5
Wilson- Russell Hill	35.1	MR300	10 8	10 x 15 8 x 12	46 44	0.9 1.1	Space	8085 7905	42.2
Russell Hill- Anderson	40.8	MR300	10	-------	45	0.9	Space	8035	42.1
Anderson- Ellis Mt.	28.3	MR300	10 10	------- -------	45 45	0.9 0.9	Space	8085 7905	44.1
Ellis Mt.- Sharp Ridge	47.3	MR300	10 10	10 x 15 10 x 15	47 46	0.8 0.8	Space	8390 8270	40.4
Sharp Ridge- Lonsdale	2.1	MR300	4	-------	37	2.2	Hot Standby	8345	52.4

TABLE 6 (CONTINUED)

PATH	DISTANCE (MILES)	EQUIPMENT	ANTENNAS PARABOLA (FEET)	REFLECTOR (FEET)	GAIN (dBi)	DW (°)	DIVERSITY	FREQUENCY (MHz)	FADE MARGIN (dB)
Rogersville John Sevier	2.8	MW508D (Collins)	4	10 x 15	37	2.3	Frequency	7805/8045 7925/8165	41.7
Landsdale-Combs Knob	31.2	MW508D	10 10	10 x 15 10 x 15	46 46	0.8 0.8	Frequency	7805/8045 7925/8165	39.6
Rogersville-Church Hill	20.3	MW508D	6 8	------- 8 x 12	41 44	1.5 0.95	Frequency	7835/8075 7955/8195	39.8
Van Leer-McEwen	15.2	MW508D	6 8	6 x 8 -------	42 44	1.2 1.05	Frequency	8045/8225 8135/8315	41.0
McEwen-Johnsonville	18.8	MW508D	8 8	------- 10 x 15	44 45	1.05 0.72	Frequency	8165/8345 8075/8255	40.2
Trace Park-Jackson	27.7	MW508D	8	8 x 12	44	0.9	Frequency	8040/7850	39.5
Nashville-Germantown	11.1	MW508D	6 6	------- -------	41 41	1.35 1.35	Frequency	8165/8345 8075/8255	43.5
Germantown-Van Leer	30.5	MW508D	8 8	8 x 12 8 x 12	44 44	0.9 0.9	Frequency	8105/8195 8285/8375	40.2
Model-Grand Rivers	39.7	MW508D	8 8	8 x 12 8 x 12	44 44	0.9 0.9	Frequency	8070/8250 8160/8340	39.7
Wilson Dam-State Line	21.1	MW508A/B	6 4	8 x 12 8 x 12	42 39	0.95 0.95	Frequency	8135/8315 8045/8225	39.7

TABLE 6 (CONTINUED)

PATH	DISTANCE (MILES)	EQUIPMENT	ANTENNAS				DIVERSITY	FREQUENCY (MHz)	FADE MARGIN (dB)
			PARABOLA (FEET)	REFLECTOR (FEET)	GAIN (dBi)	DW (°)			
State Line- Pickwick	19.0	MW508A/B	6 4	6 x 8 8 x 12	41 39	1.3 0.95	Frequency	8195/8375 8105/8285	39.7
Trenton- Nickajack Dam	20.2	MW508A/B	10 10	(30 x 40)	45 45	0.8 0.8	Frequency	8195/8375 8105/8285	40.3
Monte Sano- Madison	5.5	MW508A/B	4 8	8 x 12 --------	39 44	0.95 1.1	Frequency	8160/8380 8050/8270	40.0
Jackson- Norton Hill	3.9	MW508A/B	4 4	-------- --------	37 37	2.3 2.3		8165/8345 8075/8255	48
Norton Hill- Newcastle	39.6	MW508A/B	6 6	6 x 8 10 x 15	41 43	1.3 0.78	Frequency	8105/8285 8195/8375	39.6
Newcastle- Cordova	32.5	MW508A/B	8 8	8 x 12 8 x 12	44 44	0.95 0.95	Frequency	8045/8135 8225/8315	40.3
Cordova Allen	23.8	MW508A/B	6 10	8 x 12 12 x 12	42 47	0.95 0.65	Frequency	8165/8345 8075/8255	40.3
Signal Mt.- Sequoyah	16	MW518	10 10	12 x 16	47	0.7	Space	7960/7840	40.5
Watts Bar HP- Watts Bar NP	1.87	MW518	6 6	8 x 10	42	1	Hot Standby	8370/8250	48.4

Periscope Antennas - A previous study[2] has indicated the possibility exists for high power levels to be coupled into a periscope antenna system when the aircraft flew in the pattern of the vertically aimed dish antenna. Testing described in Appendix A and SECTION VII have shown that the blockage afforded by the aircraft body is sufficient to reduce the power to a level of about -70 dBm. The duration of the detected signal is on the order of 1 or 2 seconds. In view of the measured results overhead interference of periscope antenna systems is no longer considered a problem.

Offset Periscopes and Elevated Reflectors - Many systems use a modification of the standard periscope antenna in which the periscope reflector is placed on some convenient structure or on a nearby hill. These systems can have the parabolas beam aimed at elevation angles where the aircraft will encounter them at distances where the propagation loss is much less than at 170 miles and where the aircraft fuselage does not provide any blockage. This situation will exist for antenna beam elevation angles between 0 and 20°. There are three such systems in the TVA environment and these are listed in Table 7. From a generalized standpoint the most severe impact is to the Lonsdale site which could experience an interference level 14 dB above threshold. Since this link is a frequency diversity system the actual impact is not great. The other two systems still have positive interference to threshold levels of 1 and 2 dB.

The Sequoyah receiver operates space diversity and might require protection. However, its operating frequency is in a portion of the band not expected to be used by the aircraft unless the satellite frequency plan is changed.

TABLE 7

SITE NAME	BEAM ELEVATION	BEAMWIDTH	DISTANCE	Δ PATH LOSS	INT/THRESHOLD	FREQUENCY
SEQUOYAH	1.5/2°	0.9	80-120	7 dB	2 dB	7960
						(Collins 518)
NICKJACK	1.5°	0.8	90-120	6 dB	1 dB	8195
						8375
LONSDALE	14°	0.9	16 mi	21 dB	-14 dB	7925
30 x 40						8165

SYSTEM CONSIDERATIONS BONNEVILLE POWER ADMINISTRATION (BPA)

General - In the frequency range of interest, 7.9 to 8.4 GHz, the BPA system is almost exclusively frequency diversity. There are three non-diversity links, none of which use midpath reflectors, and there are no space diversity systems.

The general system can be typified as having path lengths much longer than those of TVA. There are four paths longer than 60 miles and over ten longer than 50 miles, 22 greater than 40 miles. While all these systems are frequency diversity, there might be some concern regarding the longer paths. As described in Reference 22, the 70 and 80 mile paths experience severe fading characteristics during the summer months.

In addition to the long paths, there are 19 paths utilizing midpath reflectors. Of these, sufficient data was available to approximate the elevation angles of the main beams of 10 sites. Of these ten, four had elevation angles which fall in the critical range. This is the area in which the interaction distance for the main beam is greatly shortened without the introduction of any attenuation due to fuselage blockage.

TABLE 8

SITE	DIST	ELEV ANGLE	PATH DIFF
SICKLER	65	3°	-9
MARION	60	3.5°	-9
TACOMA SUB	50	4.5°	-11
BIG EDDY	40	5.5°	-13

Table 8 lists the systems which are affected by the elevated antenna beam. The Path Diff column indicates the potential S/I degradation over

that of the baseline site at McEwen. It should be noted that terrain effects have not been considered. The remaining nine sites should be investigated to determine the elevation of this main beam only if the protection afforded by their frequency diversity is unacceptable.

The longer paths (80, 70 and 60 miles) are designed to a 35 dB fade margin. The longer paths cause 12, 11 and 9.5 dB more loss, respectively. Operation of the airborne SHF SATCOM terminal at 10 kW on-tune in the main beam of these systems will almost certainly squelch one side of the diversity system.

The three non-diversity hops appear to be the only truly vulnerable portions of the network. Two of the three are very short hops 8 and 4 miles and can expect little fading. In addition, their interference fade margins can be expected to be at least 6 and 12 dB better than the baseline system, i.e., instantaneous worst case interference power 11 and 17 dB below the maximum acceptable. These sites are as follows:

RX	FREQUENCY	TX	DIST	AZ
Chehalis Sub	7965	Chehalis	4.3	180°
Clatop Sub	8075	Megler	8.6	349°

The remaining hop, Squak Mountain to Snoking Sub is over a 22.3 mile long path. This hop will operate with a 4 dB interference fade margin during the worst interference situation, slightly less than that of the baseline system.

RX	FREQUENCY	TX	DIST	AZ
Snoking Sub	8230	Squak Mountain	22.3	343°
Squak Mountain	8350	Snoking Sub	22.3	163°

This system could be protected but due to the pessimistic nature of the interference computations and probability assessments, it is believed there will be little or no impact. In addition, with non-diversity hops the interference threshold which was used was the same as the squelch point for the diversity systems. For a diversity system, this is an on/off situation where if the squelch threshold is exceeded one side of the system shuts off. This occurs well before there is any noticeable degradation to the actual data. In a non-diversity system, fades which could cause this threshold level to be reached or slightly exceeded would still pass information at a substantial signal-to-noise ratio. The degradation would therefore be graceful.

SUMMARY OF SYSTEM STUDY

Examination of the two rather extensive microwave networks has shown no real cases of troublesome interference. While a few systems do vary considerably from the baseline study, other operating parameters have mitigated the interference potential.

TVA - The space diversity system at Sequoyah might require protection in the future if the airborne SHF SATCOM system alters the satellite frequency plan.

This will not be necessary if the airborne SHF SATCOM system operates at powers less than 5 kW.

BPA - No serious problems were noted. The link to Snoking Substation has a potential for being slightly more vulnerable than the baseline system.

The use of frequency diversity on long hops is the only thing protecting these systems from being extremely vulnerable.

CONCLUSIONS*

1. Interactions between the airborne SHF SATCOM terminal and multi-voice channel FDM/FM links is expected to be minimal.

2. Outage probabilities resulting from operation of the airborne SHF SATCOM system at 10 kW and flying through the main beam of any non diversity link once per day should not exceed:

20 mile path	6×10^{-6} (3 minutes per year)
40 mile path	4×10^{-5} (20 minutes per year)

3. The use of frequency diversity provides significant protection against interference.

4. Operation of the airborne SHF SATCOM terminal at powers in the vicinity of 1 kW should have no impact on the environment (FDM/FM) as presently configured.

*See Assumptions in SECTION II.

SECTION VI

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION (ERDA/AEC) MEASUREMENTS AND ANALYSIS

INTRODUCTION

This section presents a summary of the measurement and analysis factors necessary to evaluate potential interference problems between the airborne SHF SATCOM terminal and the Energy Research and Development Administration (ERDA, formerly AEC) microwave receiving systems operated at the Nevada Test Site (NTS). After discussions with ERDA personnel two systems were selected as requiring analysis and test. Summary descriptions are presented of the Nevada Automatic Diagnostic System (NADS) and the Closed Circuit Television (CCTV), including those characteristics required in the system analysis. The closed system (ground tests) and the open system (flight test) type of measurements used for the analysis are described. Probability factors necessary to take into account the random flight path of the SHF SATCOM aircraft and the statistical fading characteristics of the microwave signals are also described.

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION MICROWAVE SYSTEM

ERDA has obtained frequency assignments for microwave links in the 7900 to 8400 frequency range. The frequencies are used at the Nevada Test Site (NTS) for remote monitoring of events. Nevada Automatic Diagnostic System (NADS) is the most important type of link. Closed Circuit Television (CCTV) is also relayed by microwave links. A typical communications network at NTS is shown in Figure 25 which includes mobile vans, passive reflectors and the main receiving center CP-1C. Five NADS links may be configured at one time which includes NTS Areas 5, 12, 20, a link to one of the 2, 8, 9 or 10 areas and a link to forward areas from Echo Peak. Echo Peak is a NADS relay point.

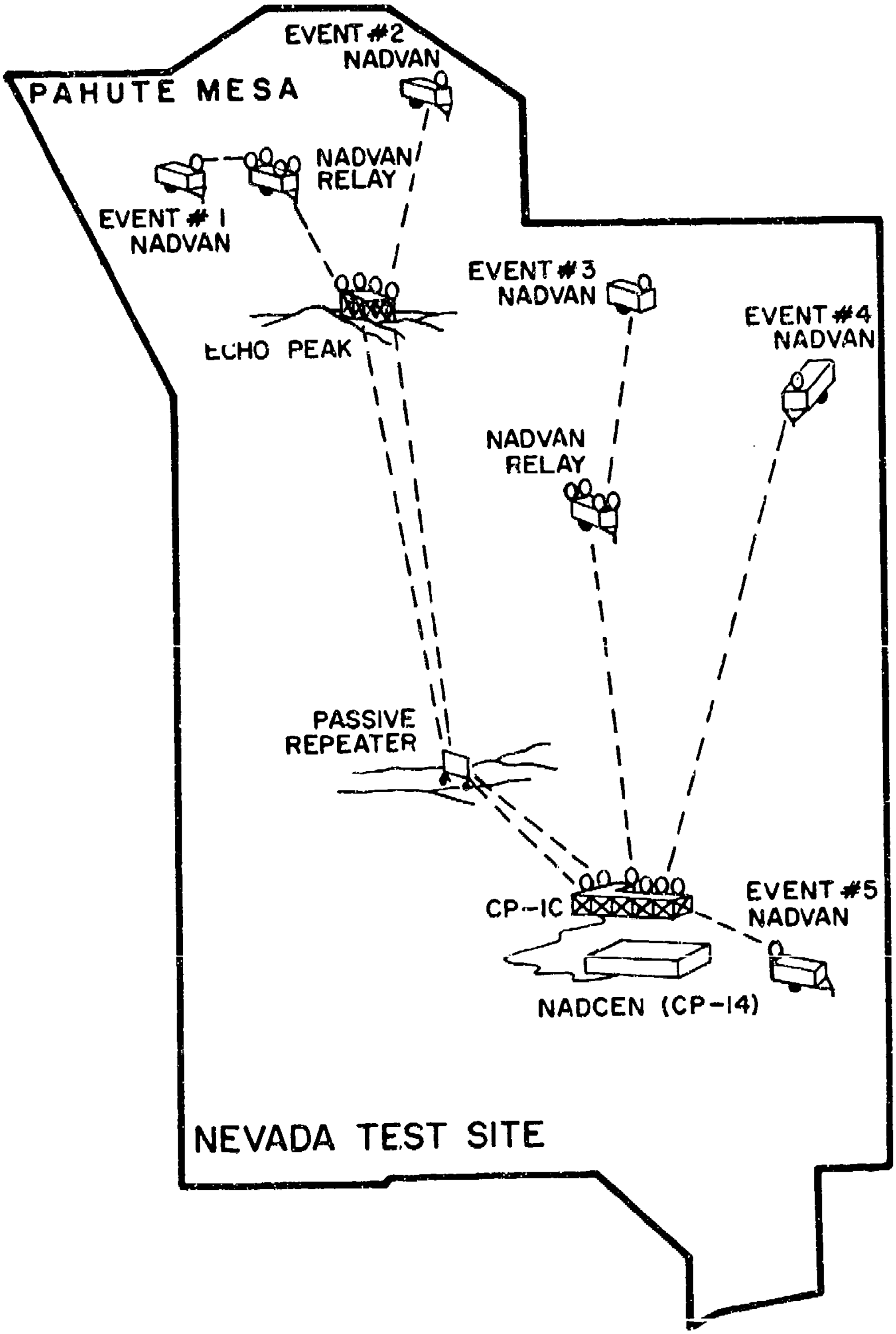


FIGURE 25 NADS COMMUNICATION

The NADS system uses wideband microwave links for transmitting data. The present system can operate at 10 or 23 Mbps data rate using Frequency Shift Keying (FSK) modulation. The RF bandwidth for the NADS system is 30 MHz with an IF bandwidth of 19.2 MHz. There are plans for upgrading the NADS link which operates on 7775 MHz to handle data rates as high as 320 Mbps and use PSK quadriphase modulation techniques. The present NADS links utilize four and six foot diameter parabolic reflector type of antennas as well as some passive reflectors. The mobile vans will have deployment areas which can be depicted as an arc which is centered at the adjacent relay point (for example, NADVAN - EVENT #2 may be deployed within an arc centered on Echo Peak). The mobile vans are deployed as required for the various test programs. The NADS assignments include approximately 13 frequencies. Of these the following are in the band of interest: 7903.1, 7962.3, 7962.5 and 8087.5 MHz.

The equipment used by NADS was manufactured by TerraCom. Associated with the NADS link was a signal conditioner, a bit synchronizer and an error counter for performing bit error rate measurements. The transmitter site had a pseudo random type of code generator.

The closed circuit television (CCTV) system at the Nevada Test Site is primarily used for security surveillance. Lenkurt Model 76 microwave equipment is used to relay the video information from an event location to a remote site. The CCTV links use a combination of parabolic reflector type of antennas and some passive reflectors. There are at least eight frequencies in the band of interest which can be used for the CCTV links. With the selection of frequencies available for CCTV it is possible to operate the entire system and not use any selected portion of the 7.9 to 8.4 GHz spectrum.

ANALYSIS OF CHARACTERISTIC REQUIREMENTS

The system characteristics specified by ERDA for the NADS and NTS-CCTV are summarized in Table 9. The NADS and CCTV $(S/N)_{IN}$ and fade margin values shown were those calculated for the particular links that were specified. The NADS link that was tested had a received signal level of -43 dBm. The NADS 10 nm link which was tested had a 26 dB fade margin.

GROUND TESTS

General - The purpose of the ground test was to measure in a closed link configuration the receiver characteristics required for the interference analysis and the SHF SATCOM airborne test. The ground tests were conducted at the Nevada Test Site on 16 to 19 December 1974.[11,12]

NADS - The test equipment diagram for the ground tests at the NADS van is shown in Figure 26. Test signals were coupled into the receive waveguide along with the desired signal. The receiver parameters measured in the ground tests for the NADS link were:

1. AGC output voltage
2. Quieting slot noise
3. Slot interference power for PN, noise or CW interference
4. Bit error rate (BER) performance with PN, noise and CW interference.

The AGC voltage was used to monitor the input desired signal level. The AGC characteristic is shown in Figure 27. The slot noise was measured at a 1248 kHz frequency offset from the carrier frequency. The desired signal could not be slot filtered at the source without causing degradation to BER. The quieting slot noise curve is shown in Figure 28. The curve was obtained with an unmodulated desired signal (CW). The curve shows

TABLE 9

ERDA NTS EQUIPMENT CHARACTERISTICS

NADS

- Digital ($P_E = 10^{-6}$)
- RF Selectivity = 30 MHz
- BW_{IF} = 40 MHz (specified); 19.2 MHz (measured)
- $BW_{BB} \simeq$ 10 MHz
- D_{PK} = 4 MHz
- $(S/N)_{IN}$ = 35 dB
- NF = 13 dB
- No Preemphasis
- Path Length = 20 miles
- Fade Margin = 21 dB (specified); 30 dB (measured)
- Required $(S/I)_{IN}$ = 18 dB
- Desired Receive Signal = -50 dBm

NTS Mobile CCTV

- TV $(S)_{IN}$ = -13 dBm (specified); -37 dBm (measured)
- BW_{IF} = 32 MHz
- BW_{BB} = 8.2 MHz
- D_{PK} = 4 MHz
- $(S/N)_{IN}$ = 75 dB
- NF = 12 dB
- Fade Margin $\geq$ 62 dB + PG
- No Preemphasis
- Path Length = 20 miles
- Required $(S/I)_{IN}$ = 6 dB

KEY FACTORS

- NADS
  - No Diversity
- NTS Mobile CCTV
  - Fade Margin

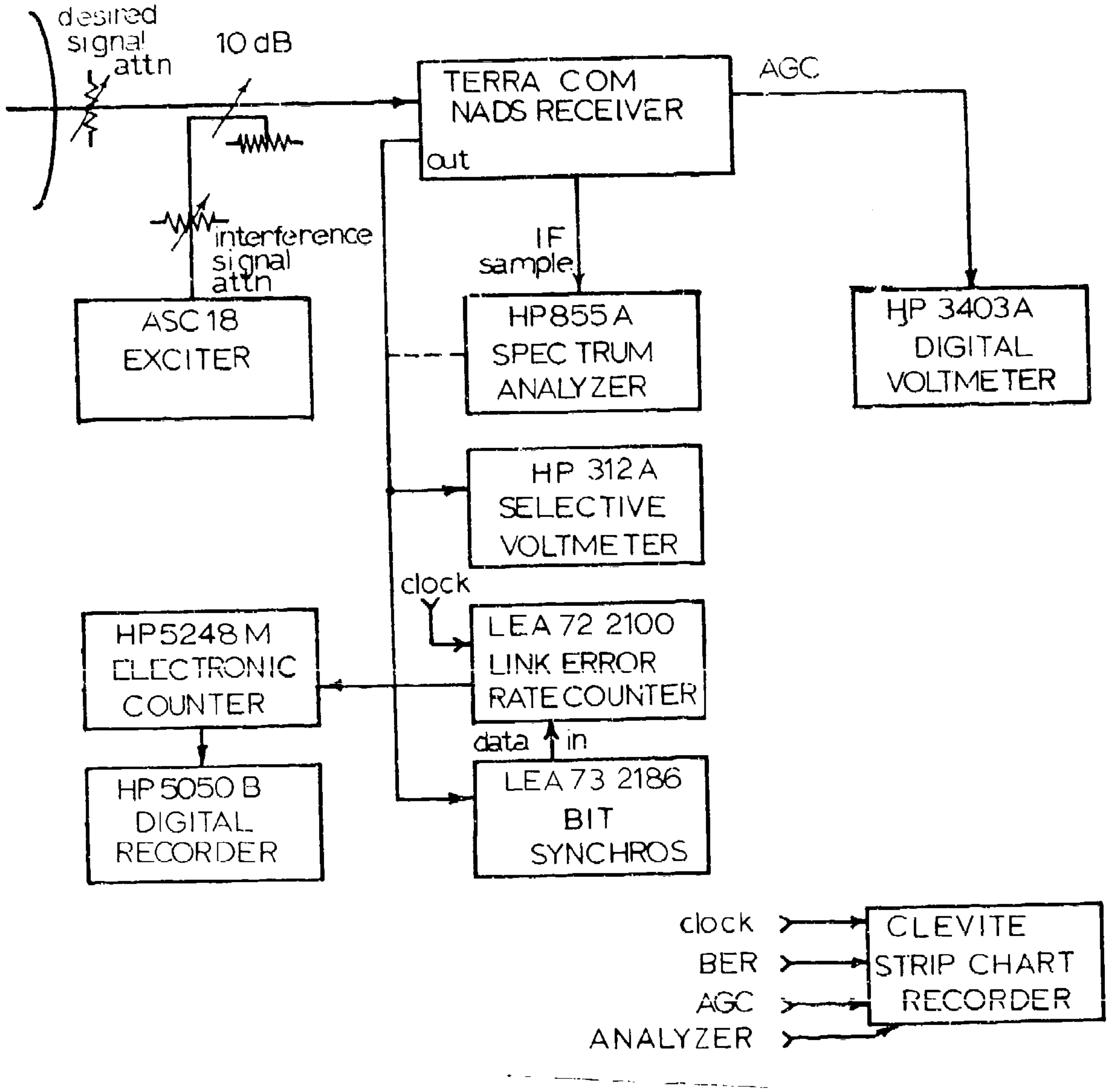


FIGURE 26 NADS GROUND TEST SETUP

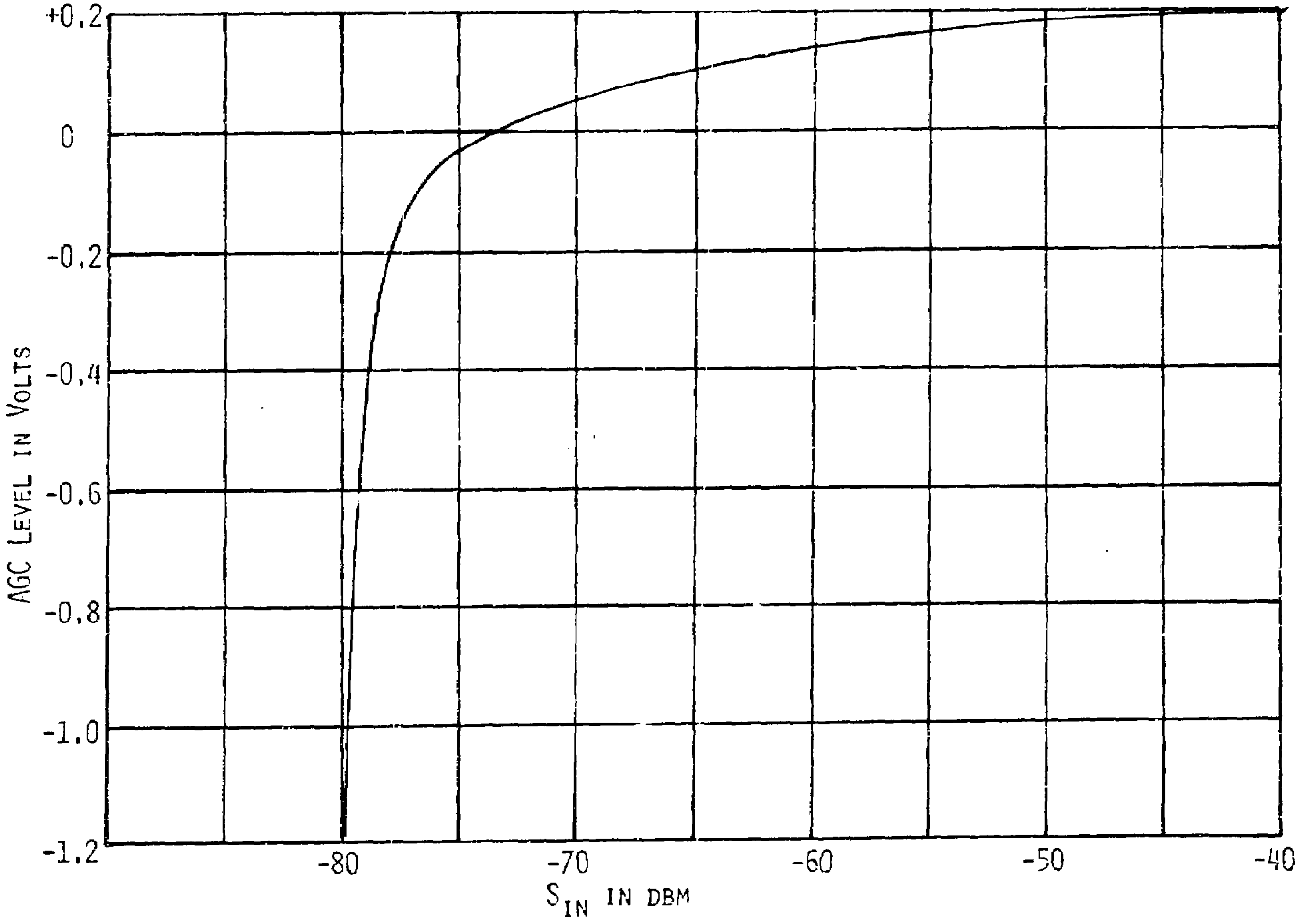


Figure 27 NADS AGC Characteristic

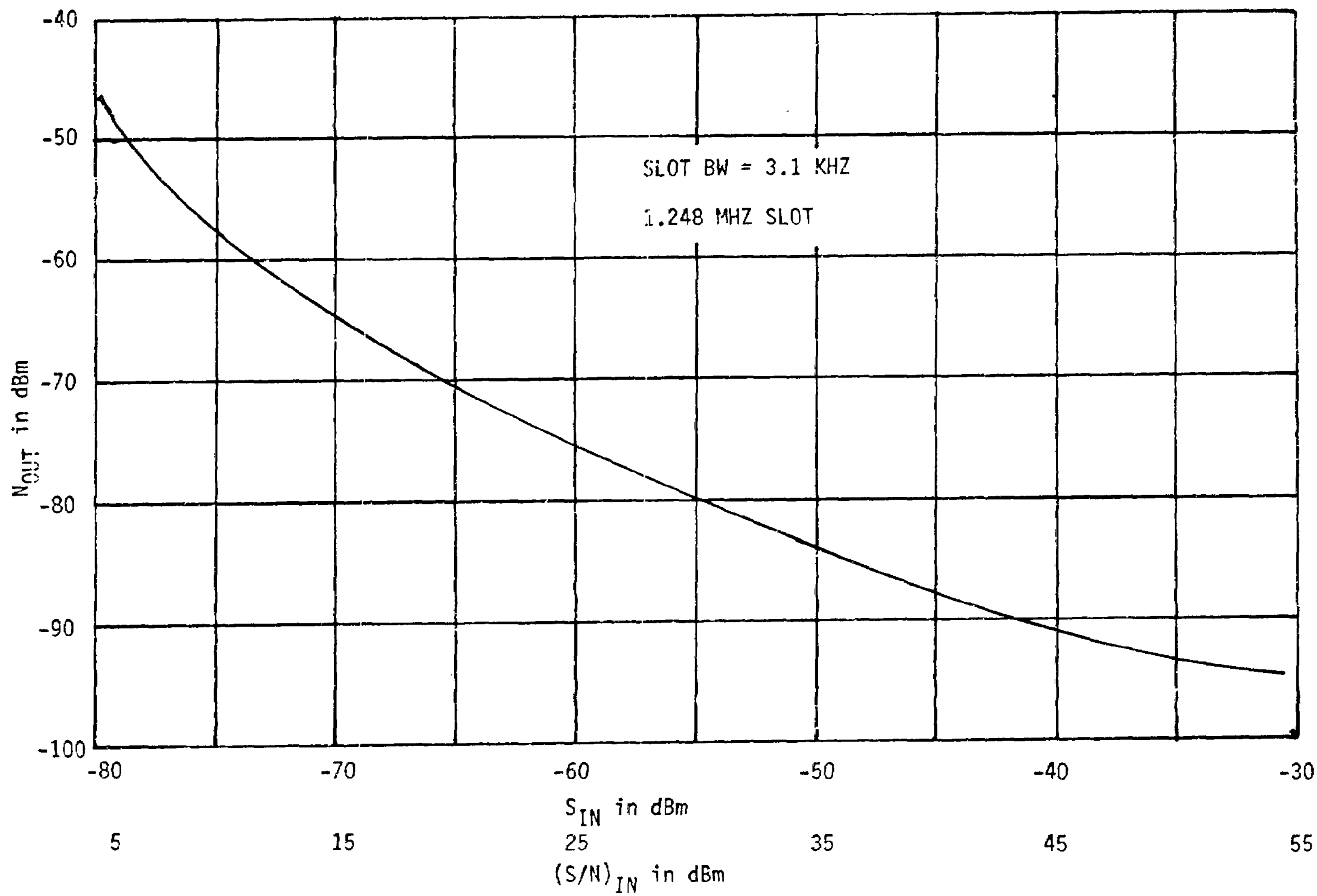


FIGURE 28 NADS CW SLOT NOISE QUIETING

slot noise as a function of input signal power level. There is a portion of the quieting curve that is reasonably linear so the following interference measurements taken over this linear operating range can be expected to be valid.

The slot noise levels versus interference levels were measured for PN, noise and CW interference. Typical results are presented in Figure 29. The PN and noise consistently provided the levels shown in this figure. CW interference, however, produced a drifting output level and only one typical curve is shown. During the slot noise test the NADS link was transmitting 10 Mbps data.

The bit error rate measurements were used to evaluate the degradation thresholds of the NADS microwave link with three types of interference, PN, noise and CW. The results are plotted in Figure 30. The theoretical performance (P_E) curve for noncoherent FSK modulation is also shown in this figure. Both PN and noise have similar measured S/I ratios for the NADS link. From the curve in Figure 30 it can be noted that an input S/I ratio of 18 dB is adequate to protect the NADS link from the airborne SHF SATCOM terminal PN type of interference. The narrowband FM interference (simulated by the CW) requires an input S/I of 2 dB for the 10^{-6} error rate. A bandwidth correction factor of 1.2 dB needs to be applied to input S/I ratio when calculating the effect of the 40 MHz bandwidth interference power on the microwave bandwidth NADS data link.

CCTV Ground Tests - For the ground test the CCTV link transmitted a "Standard Black and White Test Pattern." Evaluation of the interference effects by means of the slot noise technique was not done because the

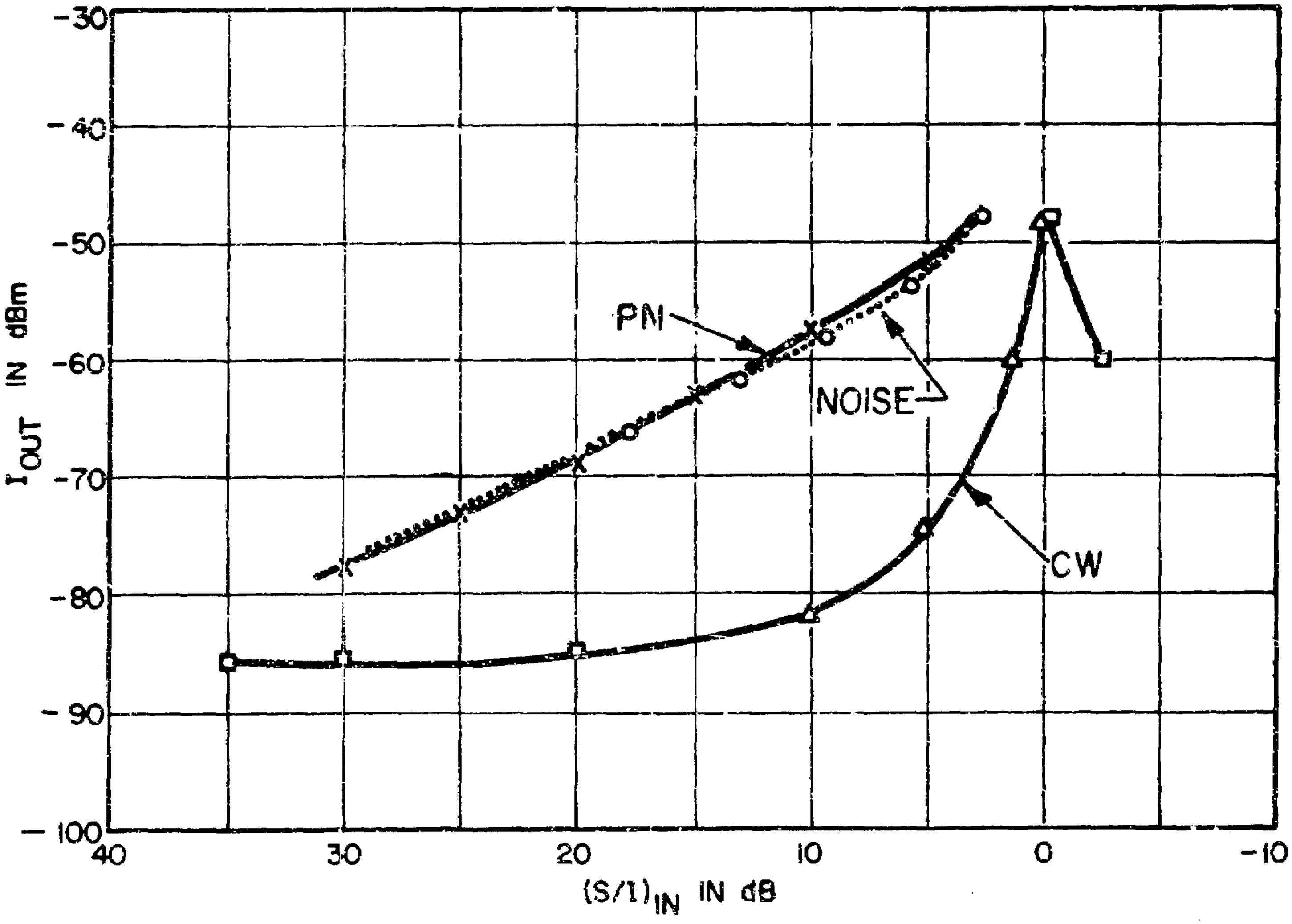


Figure 29. NADS Slot Noise versus PN, Noise and CW Interference

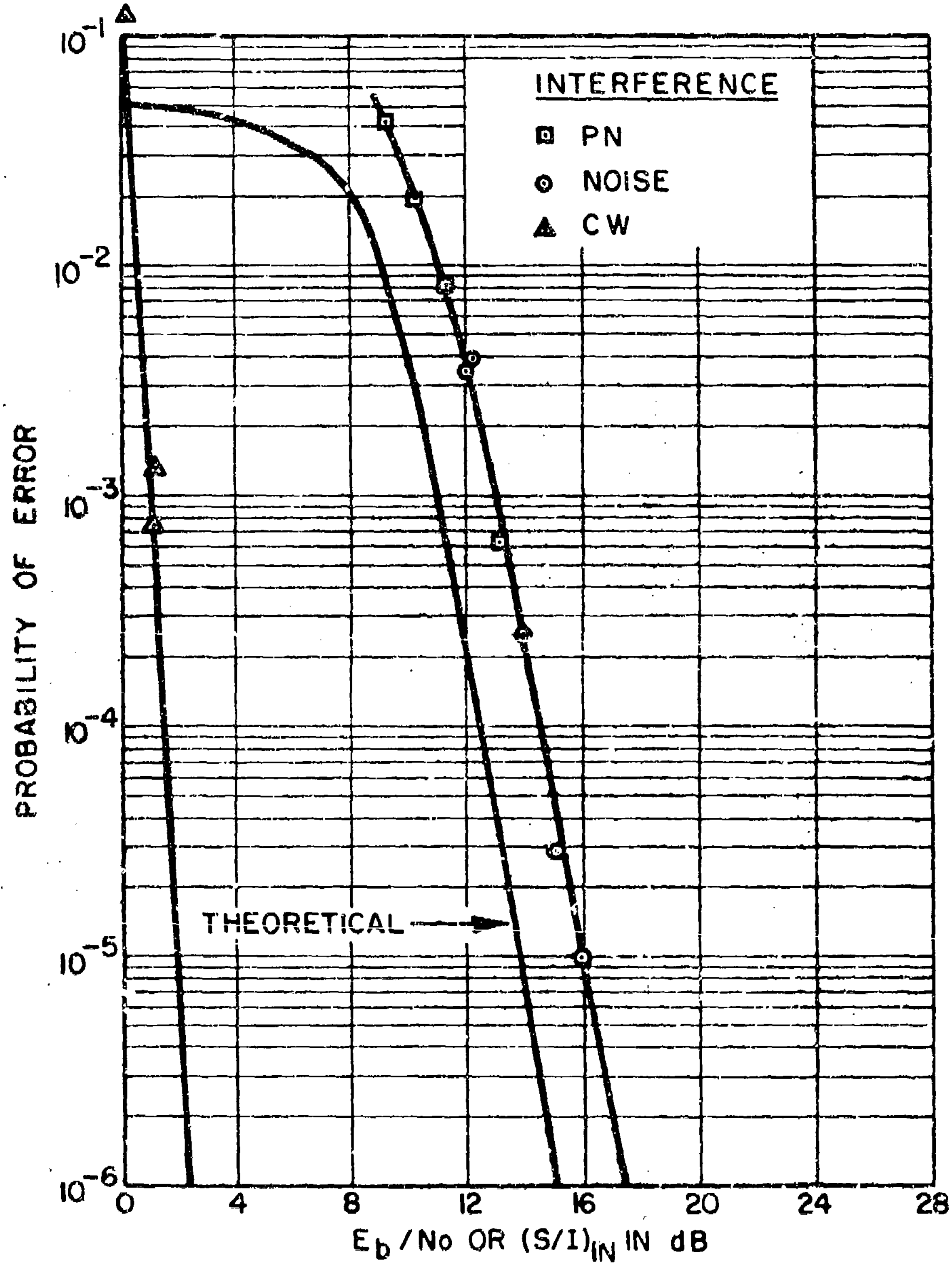


FIGURE 30 MEASURED S/I VERSUS ERROR RATE

introduction of a notch filter in the transmitted video caused a noticeable distortion to the test pattern. The test configuration for the CCTV is shown in Figure 31. The interference signals were coupled into the CCTV receive waveguide at the channel center frequency of 8037.5 MHz. The AGC characteristic of the receiver was measured. The AGC data is presented in Figure 32. The plotted characteristic is nearly a straight line which indicates that the receiver is operating within its linear range. The received signal power level was measured at -37 dBm for the 10 mile link. This signal level plus processing gain provides a link fade margin of more than 50 dB.

The effects of interference injection of PN, simulated narrowband FM (CW) and noise modulation was subjectively evaluated by observing the monitor TV display sets for the video quality. A permanent video record was obtained at this time. For interference signal levels the minimum interference threshold (MINIT) when the interference is barely discernable, was recorded as well as the maximum interference threshold (MAXIT), which represents an unuseable display. The results of this test are presented in Table 10.

The test indicated that the PN modulated signal could be tolerated by the CCTV system at a slightly higher level than could noise type of interference. This effect is probably due to a difference in amplitude distribution of the PN phase modulated signal versus the gaussian type of noise amplitude distribution. The PN signal has a relatively constant amplitude distribution while the gaussian type of noise amplitude ranges over many dB. The higher peaks of the noise interference affect the TV picture at a lower average power level than that for the PN signals. The CW interference was detectable at a lower level than the PN.

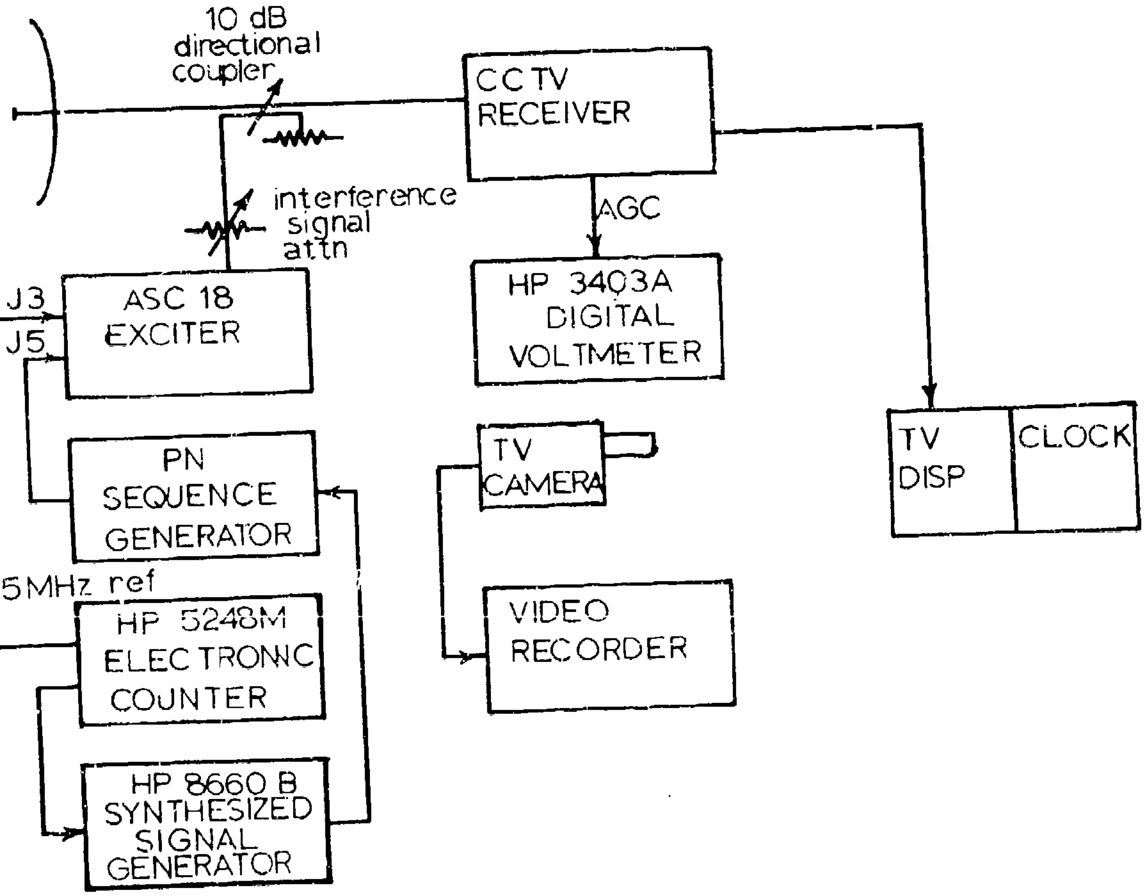


Figure 31 CCTV Ground Test Setup

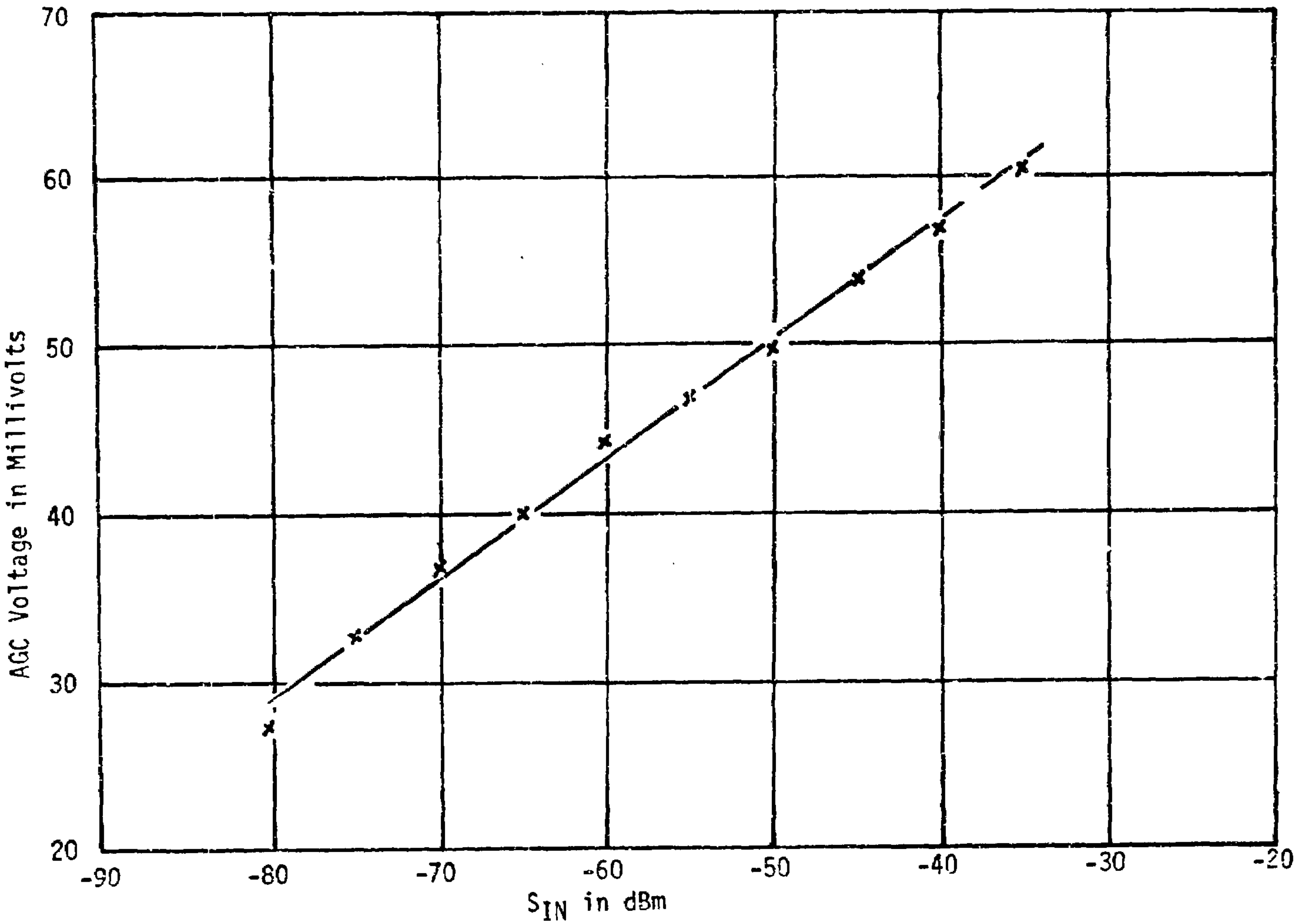


FIGURE 32 CCTV LINK AGC CHARACTERISTICS

TABLE 10

NTS-CCTV INTERFERENCE THRESHOLD SUMMARY

INTERFERENCE MODULATION	MEASURED INPUT S/I RATIO IN dB	
	MINIT	MAXIT
PN	6	2
Noise	7	1
CW	12	0

Examining the CCTV situation indicates that the high fade margin (>62 dB) in conjunction with the low MINIT requirement can protect the system from an airborne SHF SATCOM terminal emission, even if the airborne SHF SATCOM terminal without restriction operates continuously in the area of the microwave link.

FLIGHT TESTS

General - The flight tests at the Nevada Test Site were performed in order to determine the interference signal levels which could be coupled from an airborne SHF SATCOM terminal to a NADS microwave system. A flight test was not performed for the CCTV at the Nevada Test Site since the ground tests had provided sufficient information to indicate that the CCTV was not susceptible to interference.

The flight test was accomplished with the aircraft transmitting a continuous wave (CW), PN or a FH modulated signal of various power levels. The CW mode was used to investigate antenna coupling between the aircraft and the NADS microwave receiver. The PN, FH and simulated narrowband FM (CW) were used to investigate the level of degradation experienced by the NADS microwave system from antenna coupling in the main beam and from sidelobe coupling. The NADS receiver was located at CP-1 which had its receive antenna initially pointed to the north at the base of a group of hills. The test equipment configuration at CP-1 is shown in Figure 33.

NADS CW and Degradation Tests - The 18 December 1974 flight test consisted of two overhead passes with a CW, co-channel signal from the aircraft with 5 kW of power. The aircraft antenna was at 10° elevation angle and pointing in a direction toward CP-1. The received signal level was monitored with the NADS AGC voltage and the IF output level by means of a spectrum analyzer.

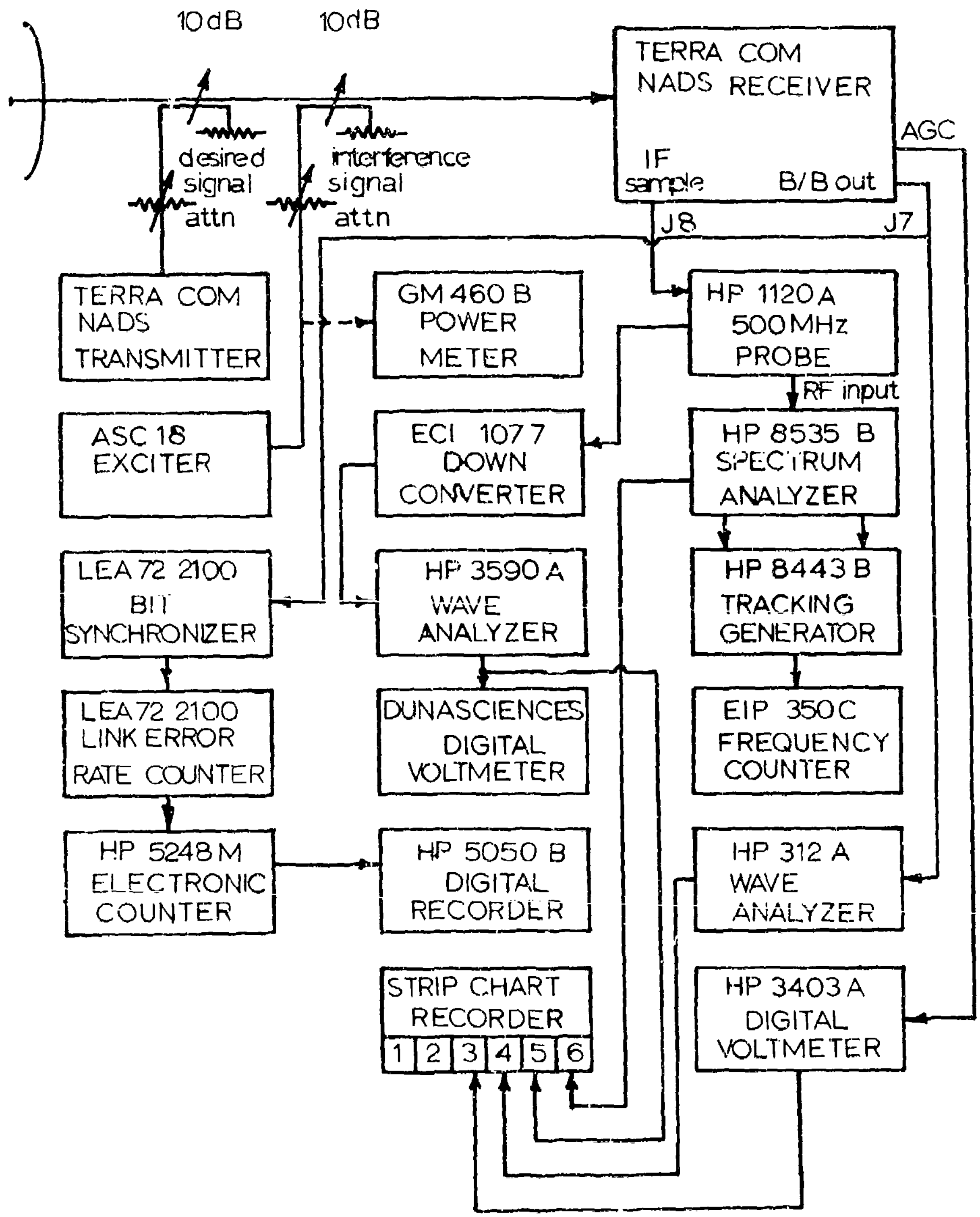


FIGURE 33. NADS AIRBORNE TEST SETUP

The test aircraft flew at 30,000 feet mean sea level (MSL) over the CP-1 site while transmitting at 5 kW. The CP-1 antenna was pointing approximately north toward the base of a group of hills which included Echo Peak. The hills provided significant terrain blockage for the CP-1 antenna main beam. The main beam of the CP-1 antenna was pointing about 1.4° below the top of some hills.

No significant received signal was received at CP-1 as the test aircraft passed directly overhead. As the aircraft flew 22 nm outbound from CP-1 the received signal indicated -95 dBm and then gradually increased to -80 dBm and became steady until the aircraft was 50 nm north of the CP-1. Beyond 50 nm the received signal fluctuated and increased to the level of -65 dBm several times. Beyond 106 nm the received signal dropped off as the local terrain blocked the aircraft signal. The second overhead pass provided similar results.

On the 19th of December the CP-1 antenna pointing elevation angle was raised to 2° in order that the main beam would be above the local terrain. The slant range from the CP-1 antenna to the 30,000 feet msl elevation plane was approximately 95 nm. Racetrack orbits shown in Figure 34 were made by the test aircraft using various modulations, two different transmitter power levels and several antenna coupling situations. The first six passes had CW modulation transmitted at 1 kW of power and the NADS receiver had no desired signal. The aircraft antenna was at 10° elevation angle and pointed in a direction toward the CP-1 antenna. The flight orbits were centered on a point located about 84 nm north of the CP-1 antenna.

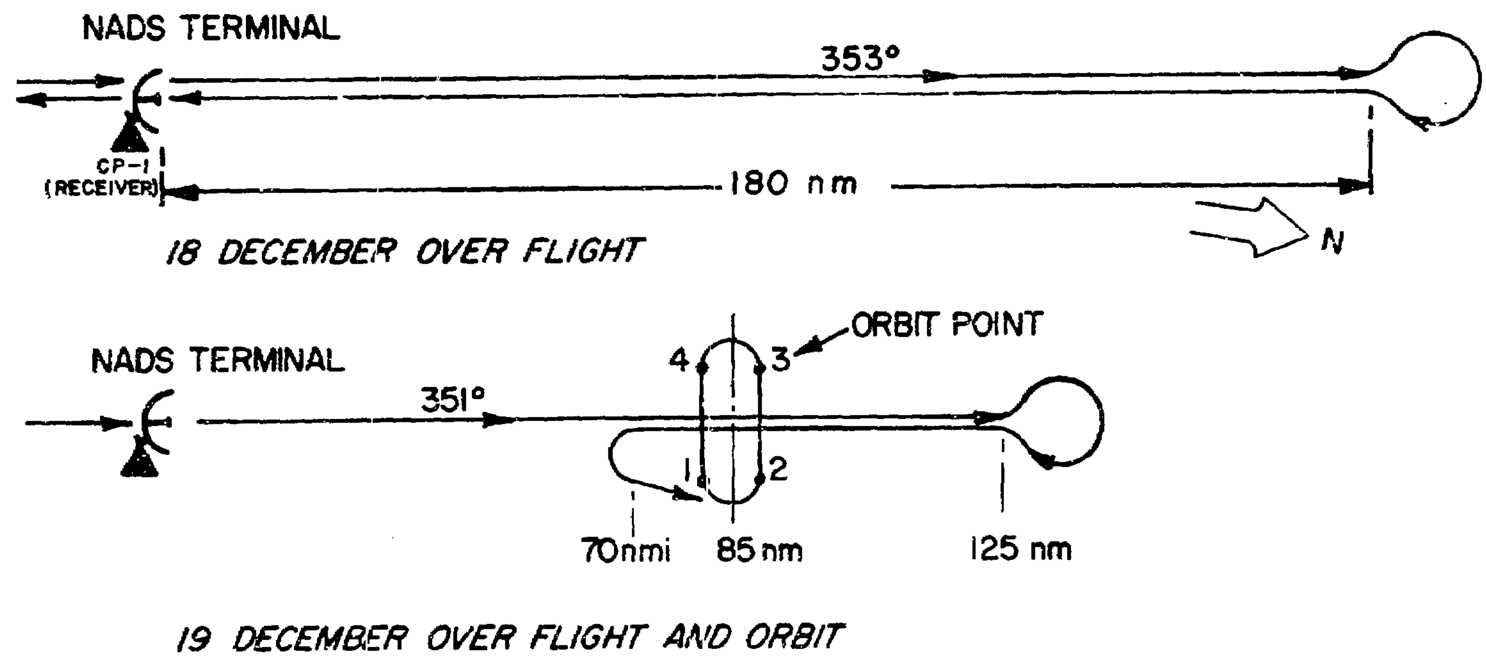


Figure 34. NADS Flight Test Geometry

At the CP-1 van the AGC voltage and the IF output were monitored and recorded in order to determine the level of the received signal during the orbits. The peak envelope of the NADS AGC voltage indicated that the following signal levels were received: -53, -55, -58, -50, -53 and -54 dBm. For the same respective orbits the received IF levels indicated -59, -83, -57, -49, -52 and -53 dBm. Considering the free space loss factor for 80 nm it appears that the test aircraft was intercepting the CP-1 NADS antenna main beam.

The remaining orbits were interference tested with the NADS 10 Mbps data link having a desired received signal level of -49.6 dBm at CP-1. The bit error rate was measured continuously as was the baseband slot noise level during the remaining 37 passes. The AGC level was recorded during the orbits and it indicated that the desired signal level was not fading. Two orbit passes with PN modulation indicated excessive bit errors for periods of 28 seconds and one for 13 seconds as the aircraft flew near the CP-1 main beam. The following three passes had the test aircraft transmitting with Frequency Hopping modulation at 1 kW. The excessive bit errors were recorded for interference periods of 32 seconds, 26 seconds and 20 seconds. All of the periods exceeded the permissible error rate for NADS of 1 in 10^{-6}.

The test aircraft transmitter power was increased to 5 kW for the final 23 passes. With the aircraft antenna at 35° elevation, pointing toward the CP-1, CW signals for two passes did not cause any bit errors. PN modulation for the 35° antenna elevation angle caused a 24 second period of excessive bit errors. Backlobe coupling from the aircraft antenna did not cause any bit errors with CW and PN modulation. Sidelobe coupling from

the aircraft antenna did not cause bit errors when CW was transmitted, but PN modulation caused a few random bit errors. With the aircraft antenna pointed at 87° elevation angle the CW interference did not cause bit errors but the PN modulation caused 13 seconds of excessive bit errors for the NADS link at CP-1. The final pass had the aircraft antenna at 0° elevation and a CW signal caused a 28 second period of excessive bit errors.

Test Summary - For the main beam coupling situation 1 kW transmit power of co-channel PN modulation caused heavy interference to the NADS link. With a NADS received desired signal level of -43 dBm, the required $(S/I)_{IN}$ ratio of 18 dB for 10^{-6} error rate would not be maintained. The received interference level was measured at -53 dBm for the aircraft at a distance of 80 nm. Thus the $(S/I)_{IN}$ was only 10 dB while the aircraft flew across the NADS main beam. It appears 1 kW of PN modulation at 2.5 times the 80 nm distance or 200 nm could provide protection to the NADS main beam as long as no fade was being experienced by the NADS link. At 200 nm the main beam $(S/I)_{IN}$ would be expected to be 18 dB. This leaves no fade margin to protect the NADS link from a SHF terminal at 200 nm with 1 kW of transmit power. At 10 kW of power any main beam interception by the SHF SATCOM terminal is predicted to create heavy interference to the NADS link.

NADS Main Beam Protection by Frequency Separation - The signal rejection of the airborne SHF SATCOM terminal emissions can be accomplished by off tuning the SATCOM transmitter from that of the NADS receiver. The TerraCom unit has a four pole preselector filter with a 30 MHz 3 dB bandwidth. The calculation for frequency dependent rejection can be accomplished

with the Off Frequency Rejection Calculation (OFRCAL) Program.[23] The program requires the emission spectrum of the 40 Mbps PN SHF SATCOM and the NADS receiver selectivity characteristics. The emission spectrum for the airborne SHF SATCOM signal is shown in Reference 3. The OFRCAL calculation indicates that 48 MHz frequency separation will provide the 48 dB of isolation needed to protect the NADS link main beam from the airborne SHF SATCOM terminal emissions at 10 kW. See Figure 35 for the computed curve of the TerraCom off-tuned frequency rejection of the airborne SHF SATCOM emission spectrum.

PROBABILITY CONSIDERATION FOR RANDOM FLIGHT PATHS

In determining the performance levels of microwave links which may receive interference from an airborne platform it is necessary to consider the statistics of both the interfering and the desired signal. Reference 19 presents the theoretical approach for analysis of this statistical problem. The technique used is to determine the probability of time that the airborne SHF SATCOM terminal can be in a given area such as the NADS antenna main beam and not increase the original equipment design outage probabilities of the microwave link.

To simplify the derivation of a digital or analog microwave system statistical performance equation, it was assumed that the desired and undesired signal can exist in two states. That is, the desired signal can be considered to exist in a faded and an unfaded state with a probability given by:

$P_{S,\ NO\ FADE}$ = Probability of desired signal not being in fade (relates to the median signal condition)

$P'_{S,\ FADE}$ = Probability of desired signal fading to a specified performance level (fade margin)

$P''_{S,\ FADE}$ = Probability of desired signal fading to the interference level

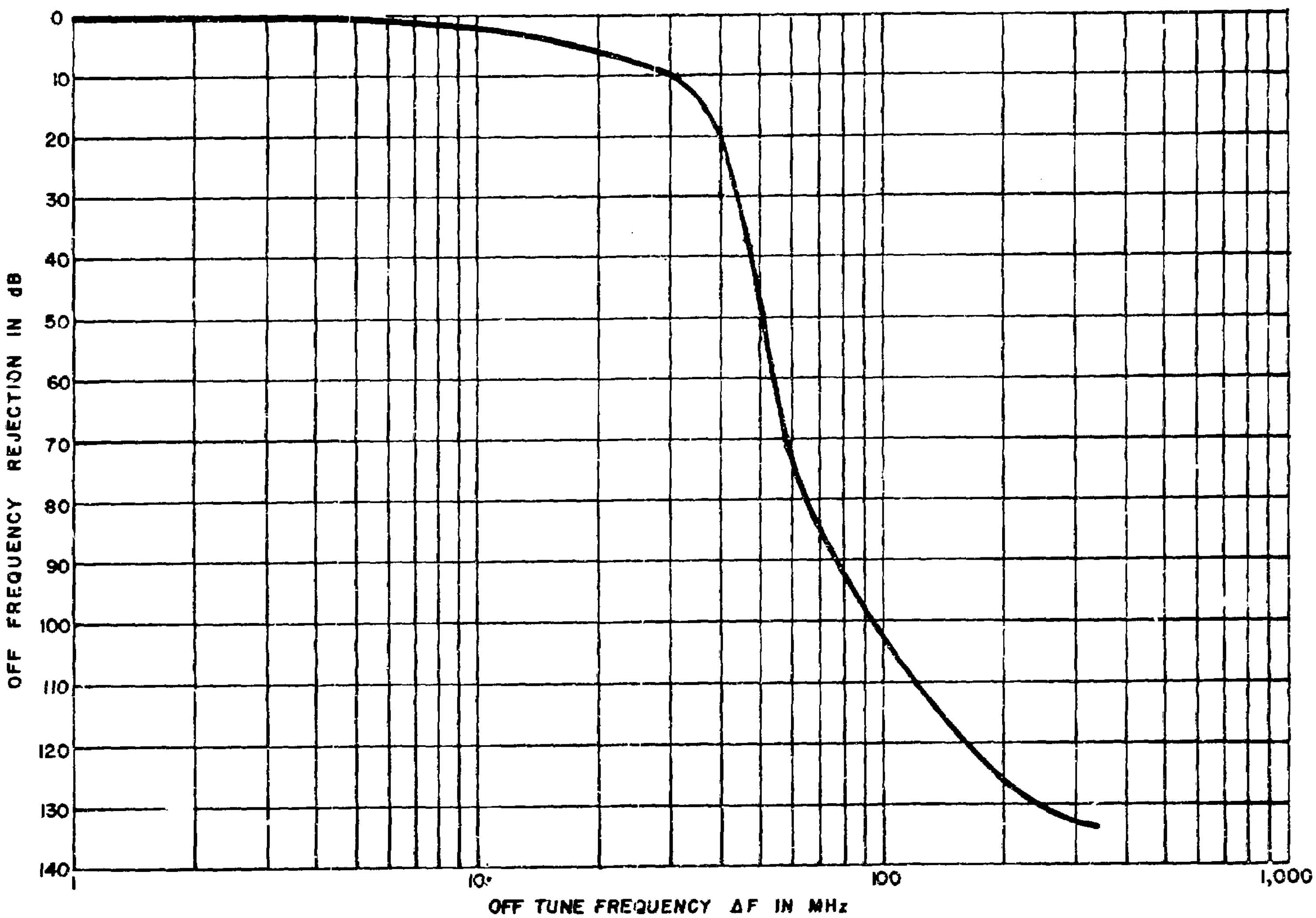


Figure 35. ASC-18 Transmitter-Terracom Receiver off Tune Frequency Rejection Curve

The airborne platform generates a source of interference which, in the most general case, is only present for random periods of time. Hence, the state of the interference signals can be defined with probability levels given by:

P_I = Probability of the median undesired (interfering) signal being present at the microwave receiver

$1 - P_I$ = Probability of the median undesired signal not being present at the microwave receiver

The interference is considered to exist only in the median signal level condition. If fading of the interference signal is considered, an additional set of probability terms would be required; however, as indicated in Reference 19, they would have little or no impact on the final interference assessment.

For each desired and interfering signal probability state a corresponding system error probability can be defined. Since there are four states, the resultant total system <u>Digital Error Probability</u> (P_E) or <u>Analog Performance</u> (PER) can be expressed by:

$$P_E = P_{S,\ FADE} \times (1 - P_I) \times P_{E,\ FADE}$$

$$+ P_{S,\ FADE} \times P_I \times P_{E/FADE + 1}$$

$$+ P_{S,\ NO\ FADE} \times (1 - P_I) \times P_{E/NO\ FADE} \qquad \text{(negligible term)}$$

$$+ P_{S,\ NO\ FADE} \times P_I \times P_{E/NO\ FADE + 1} \qquad (6\text{-}1)$$

The considerations for using the probability equations are presented in SECTION VII of this report.

For the NADS digital link the ratio of (S/I) is 18 dB. Processing gain is assumed to be ≈ 0. The probability for digital error is calculated as follows:

$$P_E \simeq (10^{-3})(1)(10^{-6}) + (6 \times 10^{-7})(8 \times 10^{-4})(1)$$
$$+ (0.5)(6 \times 10^{-9})(10^{-6})$$
$$\simeq 1.5 \times 10^{-9} \qquad (6\text{-}2)$$

The recommended values for P_I or the flight time of the airborne SHF SATCOM terminal should be equal to or less than the summarized results listed in Table 11. The P_I values are predicted to cause a negligible increase in outage time over that of the design outage time of the link.

TABLE 11

RECOMMENDED INTERFERENCE PROBABILITY VALUES

ERDA System	$(S/I)_{IN}$	P_I	Flight Time (minutes/day)
NADS	18 dB	6×10^{-7}	.001
	38 dB	6×10^{-5}	.1

The 38 dB S/I would be the value to use in selecting a possible interference contour where operation of the airborne SHF SATCOM terminal would have a negligible effect on the NADS link.

INTERFERENCE CONTOURS FOR NADS

Interference contours over a range of S/I values can provide information as to the permissible area of SHF SATCOM terminal operation for a given set of conditions. An example of an interference contour has been included for the NADS link deployed in NTS Areas 2, 8, 9 and 10 which sends data directly to CP-1. This link may operate on four frequencies of interest, 7903.1, 7962.3, 7962.5 and 8087.5 MHz, which could receive interference from the airborne SHF SATCOM terminal. The NADS transmitter was assumed to be deployed in the area between the Belted Range and Bald Mountain. This

situation would provide significant terrain shielding to a co-channel aircraft terminal operating to the northwest of the NTS. The valley floor between the mountains, however, could permit the NADS main beam a clear line-of-sight directly to the north and for several degrees of azimuth to the northeast. The interference contours for S/I ratios of 8 dB, 18 dB and 28 dB for this example are presented in Figure 36. Note that for 10 kW of airborne SHF SATCOM terminal co-channel signals an S/I of 28 dB will permit the aircraft terminal to fly directly over the NADS receiver area and out to 40 nm in front of the NADS antenna. The main beam coupling area, however, can not tolerate through flights. The wide azimuth area for the main beam is due to the mobile deployment area for the NADS transmitter.

Note that where main beam coupling is possible that the restricted areas R4809, R4807 and R4808 do not provide adequate areas within which interference protection can be achieved for NADS.

Considering that from 2 to 5 NADS links may be configured at the same time at the Nevada Test Site, then it is possible that NTS areas in addition to the one shown may require similar interference protection areas.

Coordination with the NTS frequency manager is essential if the airborne SHF SATCOM terminal intends to operate adjacent to the NTS restricted areas with a frequency overlapping the 7900 to 8087 MHz frequency band.

OPERATIONAL CONSIDERATIONS

ERDA-NADS - At the NTS currently four frequencies are of interest (7903 to 8087.5). If these could be deployed in the shortest hops or at locations were terrain shielding is significant, and if other frequencies could be

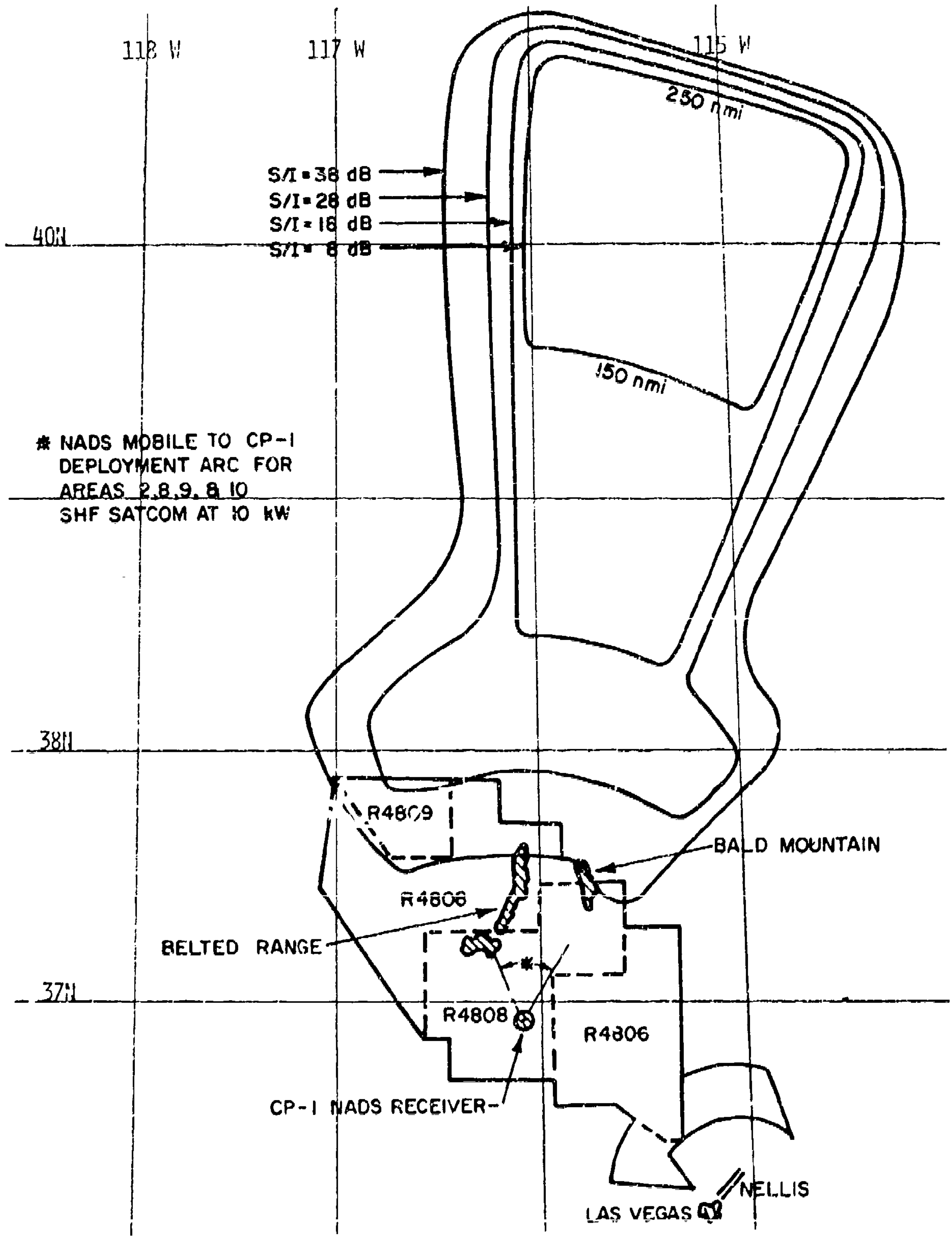


Figure 36. Interference Contours for NADS 10 kW Co-channel

used with passive reflectors or with transmitting antennas located on top of mountain peaks, the interference from the SHF SATCOM would be minimized. Also if the four frequencies were not deployed in areas to the south of CP-1, interference would be minimized.

Airborne SHF SATCOM Terminal - A channel frequency separation of 48 MHz should be maintained when operating at 1 kW in areas adjacent to NTS. Coordination with ERDA is recommended if the airborne SHF SATCOM terminal is to operate within line-of-sight of NTS on frequencies in the 7900 to 8100 band.

CONCLUSIONS*

1. Due to the large fade margin for the CCTV links they are predicted to be able to maintain high quality television service with the airborne SHF SATCOM terminal operating co-channel, at high power in the same geographic area.

2. When the airborne SHF SATCOM terminal operates co-channel within 80 nm of a NADS site and in the main beam the NADS link which underwent test was susceptible to PN modulation emission of 125 watts or greater. For the specified NADS signal level the corresponding PN interfering signal level is 40 watts.

3. Operation of the airborne SHF SATCOM terminal adjacent to a S/I contour of 28 dB is predicted to have little effect on the link beyond that of the design outage time.

4. A frequency separation of 51 MHz at 10 kW (or 48 MHz at 1 kW) is predicted to permit the airborne SHF SATCOM terminal to operate in the area of a NADS link without increasing the link outage time beyond the design outage time.

*See Assumptions in SECTION II

5. The line-of-sight links between the JPL sites are in general short hops with adequate fade margin. However, one hop uses a midpath reflector which has a 10° elevation angle. That hop could be susceptible to interference due to main beam interception.

RECOMMENDATIONS

When the airborne SHF SATCOM terminal operates within line-of-sight of the NTS complex the terminal should maintain at least a 51 MHz frequency separation from assigned NADS frequencies or else coordinate the flight with NTS operations.

SECTION VII

FEDERAL AVIATION ADMINISTRATION MEASUREMENTS AND ANALYSIS

INTRODUCTION

This section presents a summary of all the measurement and analysis factors necessary to evaluate potential interference problems between the SHF SATCOM terminal and the FAA microwave receiving systems. A summary description is given of the FAA microwave system and in particular those characteristics required in the system analysis. Both the closed system (back to back) and the open system (flight test) measurements required in the analysis are described. Probability factors necessary to take into account random flight paths of the SHF SATCOM aircraft and statistical fading characteristics of the microwave signals are described. Finally, a computer program is described that generates contours, on a map, proportional to interference intensity or signal-to-interference ratio that allows a comprehensive assessment of the interference potential to the total U. S. FAA microwave environment. The following describes each of these areas in detail.

SYSTEM DESCRIPTION

General - The FAA uses two types of microwave links in the 7.9 to 8.4 GHz band for communication between radar sites and Air Route Traffic Control Centers (ARTCC) or Terminal Radar Control (TRACON) facilities. The Radar Microlink Systems RML-4 are normally associated with the ARTCC while the RML-6 systems usually support the TRACON facility operations. In general, either type of link could be used for relay purposes. The RML-4 links are generally long consisting of multihops, while the RML-6 normally support short one-hop links.

RML-4 - The RML-4 relays radar data and control information between the radar transmitter/receiver and the radar display equipment in a Federal Aviation Agency air-route surveillance radar system.[24] This system is configured as shown in Figures 37 and 38. The sites (radars, indicators and relays) use both horizontal and vertical polarization. Each link uses six 15 MHz channels. Channels 1 through 4 relay radar information from the radar site to the indicator site, while channels 5 and 6 relay information from the indicator site to the radar site.

Channel frequencies for most RML-4 systems are allocated from the ten groups of frequencies listed in Table 12. Five of the frequency groups are designated for use with vertical antenna polarization and the remaining five groups for use with horizontal antenna polarization.

The data transmitted on individual RF channels are:

Channel 1 (Radar to Indicator)	Beacon triggers, beacon video, and a 5-mc fault-sensing signal.
Channel 2 (Radar to Indicator)	Radar trigger, normal video, MTI video (nongated), and a 5-mc fault-sensing signal.
Channel 3 (Radar to Indicator)	Service channel; station alarm tones; coarse, fine and reference azimuth subcarriers, angle marked; SSB voice and data channels; noninstantaneous feedback controls; telemetry information; and a 5-mc fault-sensing signal.
Channel 4 (Radar to Indicator)	Spare for channels 1, 2 and 3, and a 5-mc fault-sensing signal.
Channel 5 (Indicator to Radar)	Service channel, RF channel switch-over tones, system alarm tones, station alarm tones, beacon variable IF gain control, (the beacon gain control channels are presently not used on RF Channel 5) instantaneous and noninstantaneous control functions, SSB voice channels, and a 5-mc fault-sensing signal.

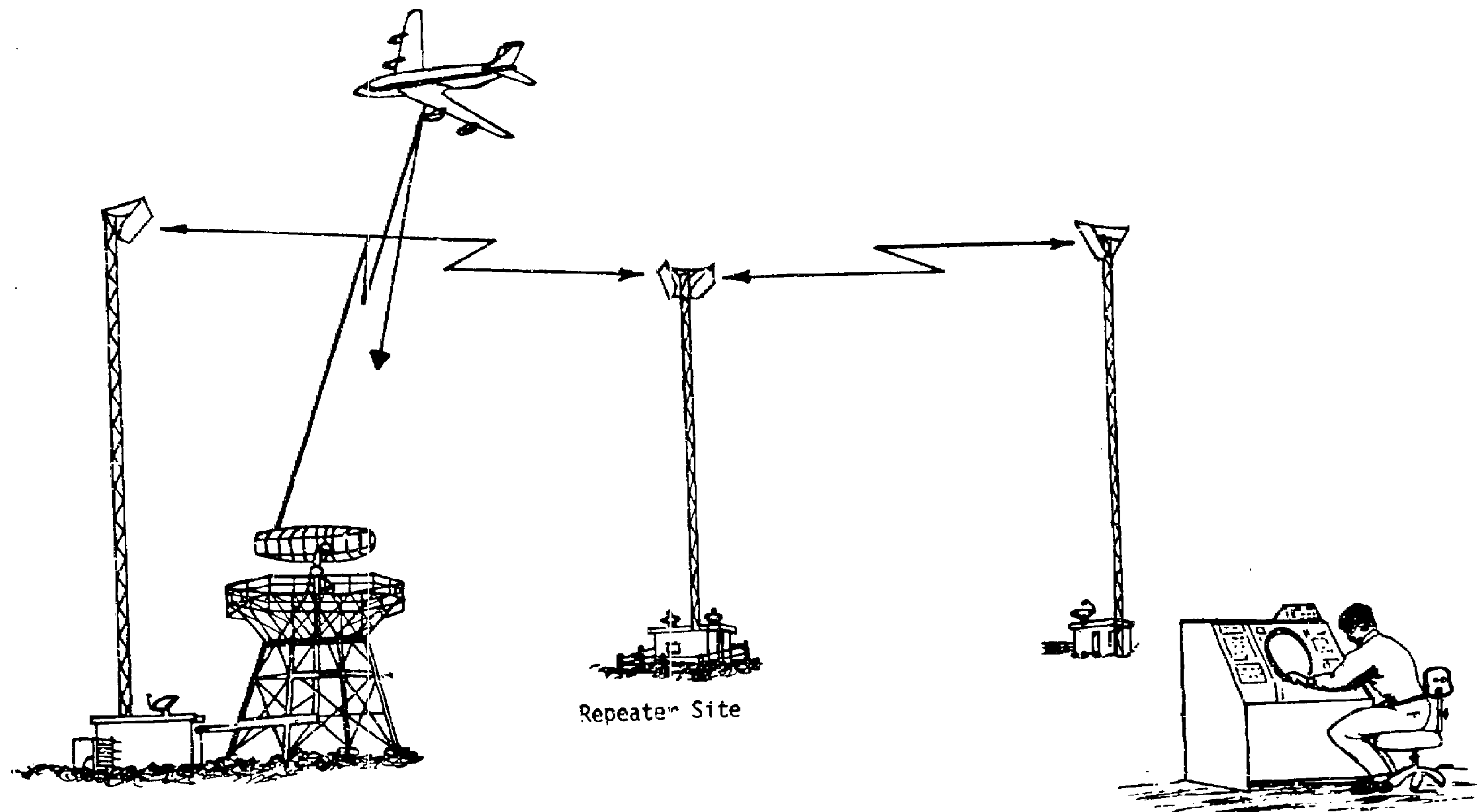


FIGURE 37 TYPICAL RML-4 INSTALLATION

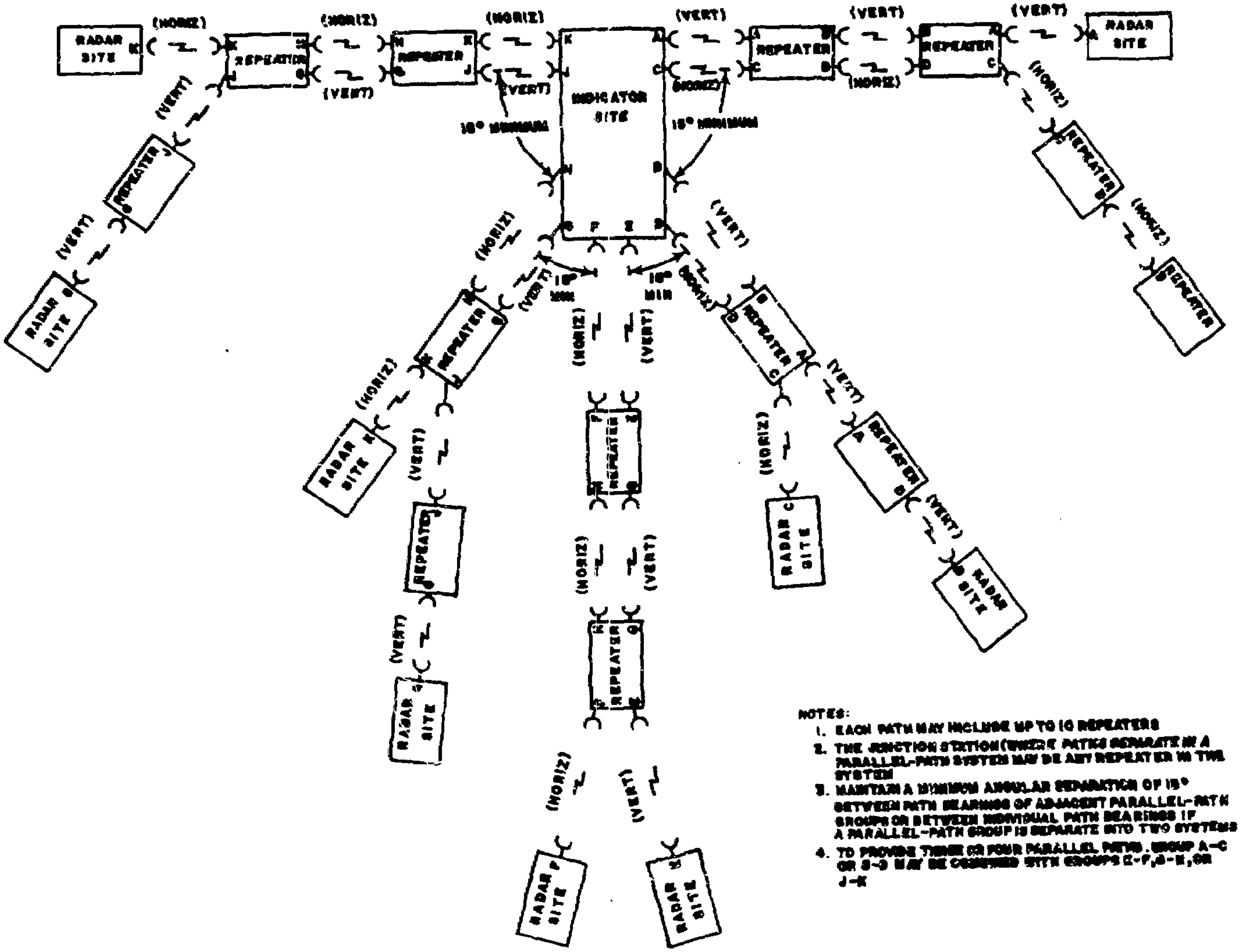


FIGURE 38 RML-4 SYSTEM CONFIGURATION

TABLE 12

LOW-BAND FREQUENCY GROUPS (7125 to 7650 MC)

Channel Number	Group A (Vertical)	Group B (Vertical)	Group C (Horizontal)	Group D (Horizontal)
1	7160	7205	7185	7230
2	7250	7295	7275	7320
3	7340	7385	7365	7410
4	7430	7475	7455	7580
5	7515	7560	7540	7135
6	7605	7650	7530	7495

HIGH-BAND FREQUENCY GROUPS (7650 to 8400 MC)

Channel Number	Group E (Vertical)	Group F (Horizontal)	Group G (Vertical)	Group H (Horizontal)	Group J (Vertical)	Group K (Horizontal)
1	7685*	7745*	7725*	7785	7765	7705*
2	7805	7865	7845	7905	7885	7825
3	7925	7985	7965	8025	8005	7945
4	8045	8105	8085	8145**	8125**	8065
5	8170**	8230**	8210**	8270**	8250**	8190**
6	8290	8350	8330	8390	8370	8310

Frequencies outlined in the block are possible frequencies with which the airborne SHF SATCOM system could interfere.

*Low-band equipment used for this frequency only in this group.

**Planned frequencies for the airborne SHF SATCOM transmitter consist of two 50 MHz bands centered at 8.150 and 8.240 GHz. These planned frequencies are co-channel with the indicated FAA frequency groups.

Channel 6 (Indicator to Radar)	Spare for channel 5, RF channel switchover tones, station alarm tones, and a 5-mc fault-sensing signal.

Figures 39 and 40 show the baseband spectrums for the six RF channels. Figure 41 shows a block diagram of the radar data transmission system.

Various antennas are used at the radar, relay and indicator sites. These include the Collins 56W1-MW Antenna (5.3 ft diameter dish using an offset feed and employing passive reflectors), the Andrews P8071G (8 ft dish, 43.5 dB gain, 1° beamwidth), and the Andrews P10-71G (10 ft dish, 45.2 dB gain, 0.9° beamwidth).

Approximately fifty Collins antennas have been replaced in cold weather areas by special MSL antennas. Measurements made by OT[25] indicate that although the beamwidth of the MSL antennas is the same as the Collins antenna at the 6 dB down point, it is approximately 50% wider at the 15 dB down point (approximately 20% at the 25 dB down point). The interference protection ratio contours discussed in latter portions of this section could therefore be wider than indicated for a small number of CONUS hops.

As can be seen from Table 12, no frequencies in the low band frequency groups (A through D) fall within the 7.9 to 8.4 GHz band. In the high band frequency groups (E through K), there are four frequencies in each group (five in group H) that fall in the 7.9 to 8.4 GHz range.

The RML-4 transmitters (six at each site) are broadband FM, either 7125 to 7725 MHz or 7750 to 8400 MHz. The transmitter has a 100 milliwatt RF power output and uses a ± 3 MHz carrier deviation. The receiver has a tangential sensitivity of -88 dBm.

At each relay site the signal is received, demodulated to baseband, remodulated and transmitted.

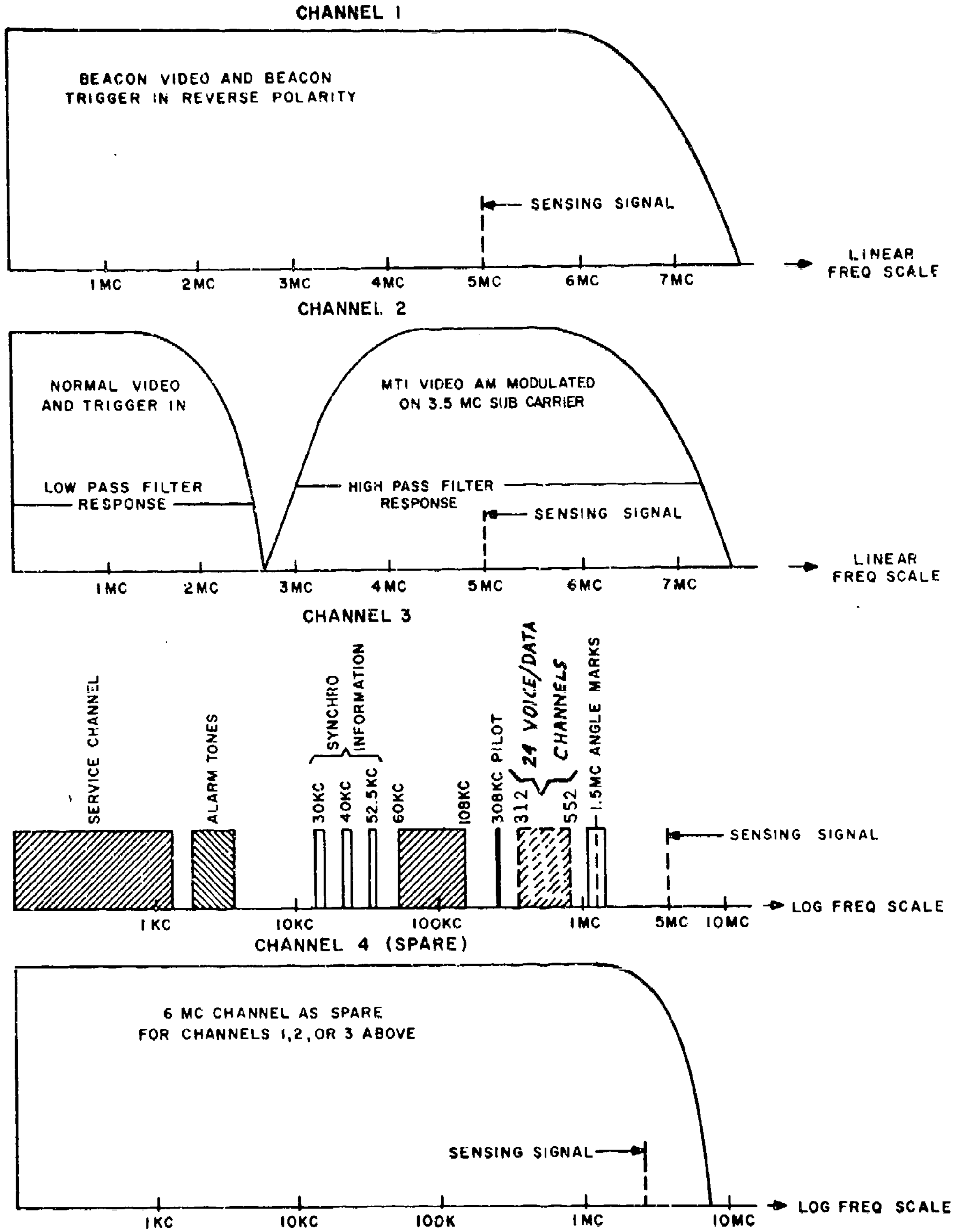


FIGURE 39 BASEBAND SPECTRUM RML-4 RF CHANNELS 1,2,3&4

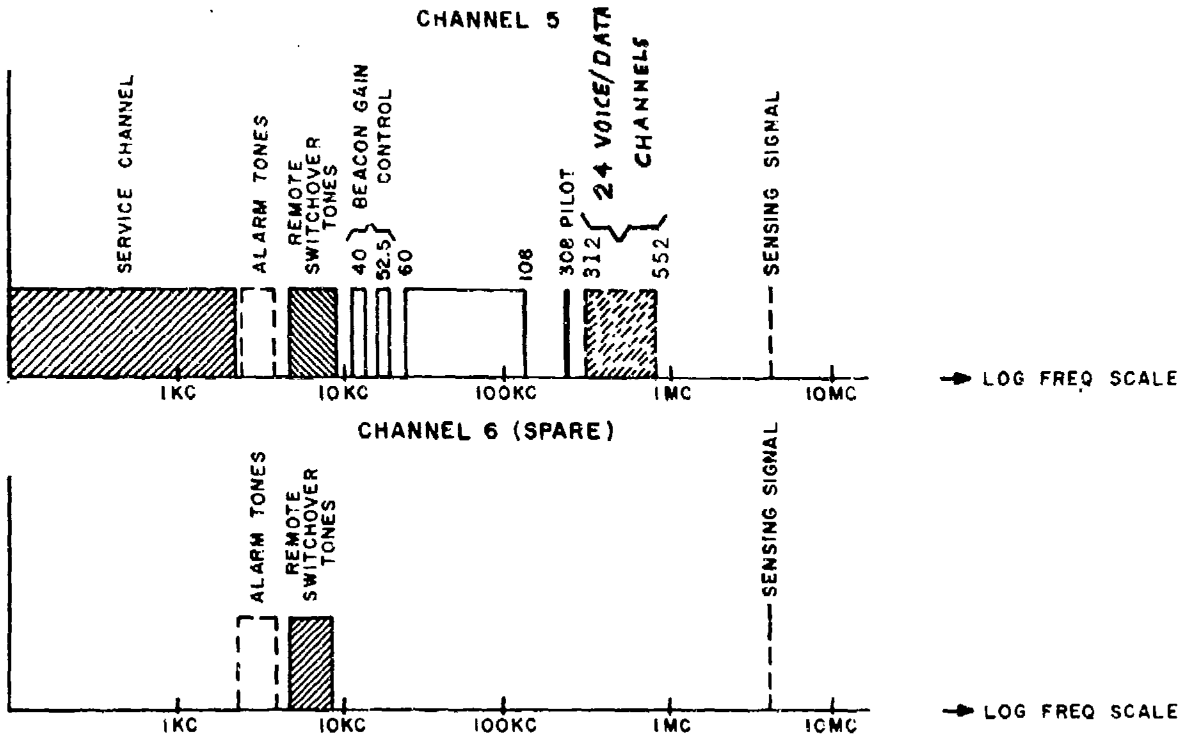


FIGURE 40 RML-4 BASEBAND SPECTRUM, RF CHANNELS 5 AND 6

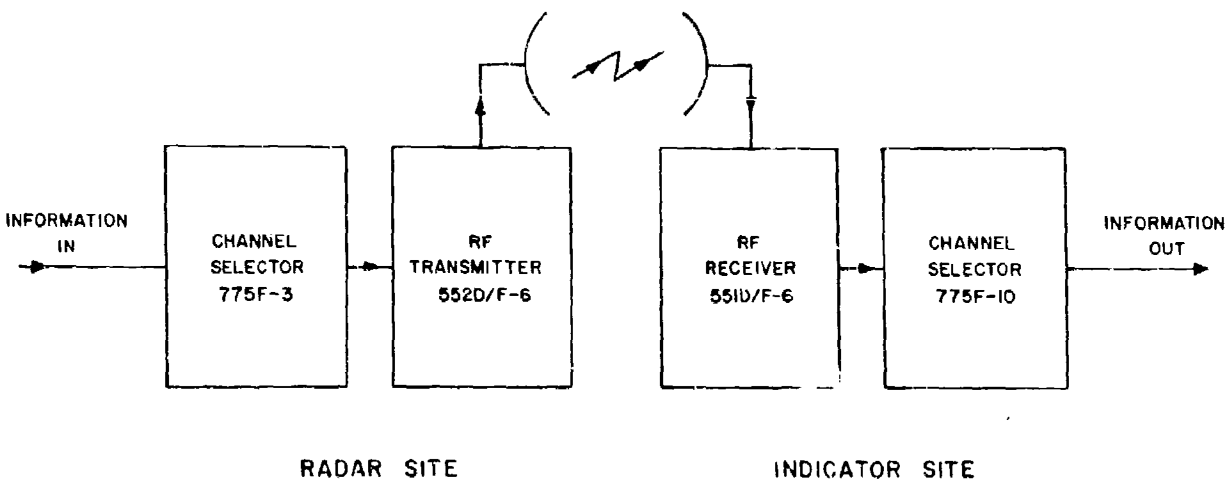


FIGURE 41 RML-4 RADAR DATA TRANSMISSION BLOCK DIAGRAM

NOTE: BASEBANDS A AND B OCCUR SIMULTANEOUSLY HOWEVER BASEBAND A IS ALWAYS NEGATIVE BASEBAND PULSES WITH TIME SHARING BETWEEN THE BEACON VIDEO AND BEACON MODE TRIGGERS BASEBAND B USES POSITIVE SIGNALS AND IS FREQUENCY SEPARATED BETWEEN THE RADAR AND BEACON PRETRIGGER SIGNALS, THE BEACON PRETRIGGER BEING DERIVED FROM A 4.1 MHZ SUBCARRIER. 2.0 MHZ MODULATION BANDWIDTH KEYED CARRIER.

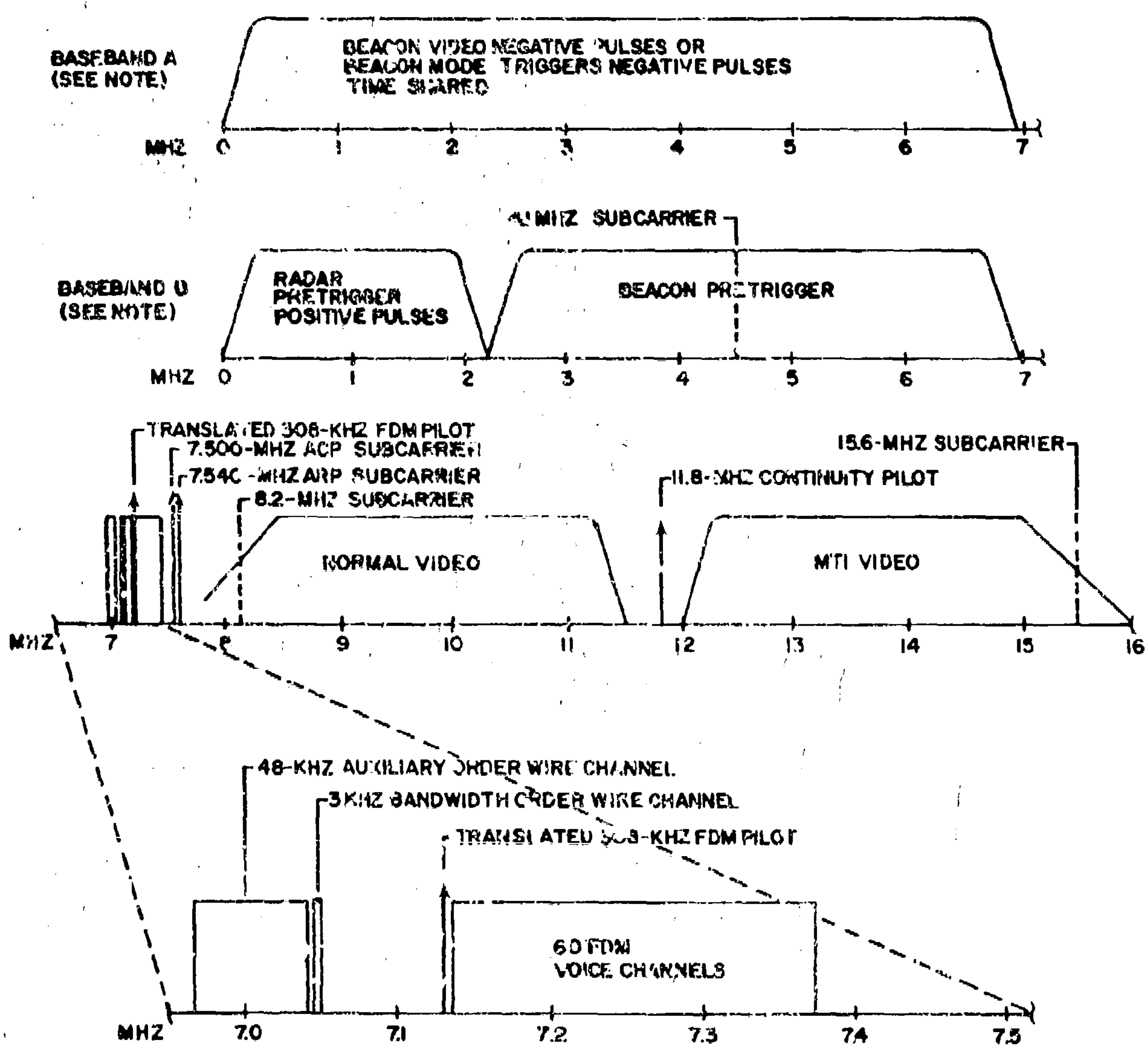


FIGURE 42 16-MHZ BASEBAND SPECTRUM

The alarm tones, voice and control tones are SSB modulation of subcarriers (voice subcarriers are in the 60 to 104 kHz range). The subcarriers are then combined to form a baseband which is transmitted via FM modulation of RF carrier.

The entire system is designed to achieve 99.95% time availability. The theoretical performance with the 5 1/3 ft, offset feed parabolic antennas used with a zero gain reflector where required is as follows:

1. For beacon video channel with 5 MHz bandwidths, 3 MHz peak deviation, the peak signal to rms noise ratio is 48.1 dB.
2. For the normal video (normal radar) signal (2 MHz bandwidth, 750 kHz peak deviation), peak signal to rms noise is 48.0 dB.
3. For a MTI channel with deviation of 1.5 MHz, peak signal to rms noise ratio is 35.4 dB.
4. The theoretical signal-to-noise (rms-to-rms) for the voice and control signals is 80.9 dB. Due to non-linear distortion a practical value is approximately 62 dB.

The above is for a one-hop, 30-mile system. This one-hop system requires a 37 dB fade margin for a 99.99% propagation reliability and 23 dB fade margin for 99.90% propagation reliability. The degradation of the above as a function of repeater spacing and number of repeaters is given in the literature.

RML-6 - In addition to the RML-4 links which operate in the 7.25-8.4 GHz band, there are RML-6 links. These are normally short one-hop links which connect major airport radars (e.g., ASR-7) to the terminal control facility. The RML-6 uses four channels, two between radar and indicator site and two

from indicator site to radar. The channel bandwidth is 45 MHz. As with the RML-4, the low band frequencies (7150-7650 MHz) are below the SHF SATCOM system's frequencies. The high band frequencies (7750-8375 MHz) are such that the radar to indicator are the highest (the reverse of the RML-4). The frequencies are given below:

High Band (7750-8375 MHz)

	Group A	Group B	
Channel 1	8375	8325	radar to
Channel 2	8100	8050	indicator
Channel 3	7800	7850	indicator
Channel 4	7900	7750	to radar

With the exception of the wider bandwidths, and being a normally short one-hop link system, the RML-6 is quite similar to the RML-4 in terms of the information relayed, type of modulation and the system reliability required. The baseband spectrum of the RML-6 is shown in Figure 42.

The RML-6 is presently used at 17 locations providing information over 12 separate paths. These locations and the frequency assignments in the 7.9 to 8.4 band are given in Table 13.

ANALYSIS CHARACTERISTIC REQUIREMENTS

The following describes those FAA performance characteristics required for the SHF SATCOM analysis. The system characteristics for the RML-4 and RML-6 links as specified by the FAA are summarized in Table 14.[1] The noise processing gain for the RML-4 link is summarized in Table 15.

The RML-4 minimum output (S/I) is 12 dB for the critical links (Normal Video; MTI Video, Beacon, Digital).

The worst case RML-4 median input signal level is given by Equation 3-5 as:

TABLE 13

FAA RML-6 LINKS IN CONUS

Frequency (MHz)	Location
7900	Davie - Miami, Florida
	Atlanta, Georgia
	Chicago, Illinois (O'Hare-McCook)
	Grapevine-Bachman, Texas
8050	Baldwin-Crawford, Florida
	Chicago, Illinois (O'Hare)
	Chicago, Illinois (McCook)
	Collyville-Grapevine, Texas
8100	Cecil Field-Baldwin, Florida
	Crawford-Jacksonville, Florida
	Atlanta, Georgia
	Chicago, Illinois (McCook-O'Hare)
	Kansas City, Missouri (Mid-Cont)
	Bachman-Grapevine, Texas
8325	Baldwin-Crawford, Florida
	Davie-Ft Lauderdale, Florida
	Chicago, Illinois (O'Hare)
	Chicago, Illinois (McCook)
	Collyville-Grapevine, Texas
8375	Cecil Field-Baldwin, Florida
	Crawford-Jacksonville, Florida
	Atlanta, Georgia
	Chicago, Illinois (McCook-O'Hare)
	Kansas City, Missouri (Mid-Cont)
	Bachman-Grapevine, Texas

TABLE 14

KEY FAA SYSTEM CHARACTERISTICS

- o EQUIPMENT CHARACTERISTIC

Analog (Beacon, Normal, MTI); $(S/I)_{OUT}$ = 12 dB

Digital (3 voice channels); $P_E \sim 10^{-5}$, $(S/I)_{OUT}$ = 12 dB

BW_{IF} = 15 MHz (RML-4), 45 MHz (RML-6)

BW_{BB} = 7 MHz (RML-4), 16 MHz (RML-6)

D_{PK} = 3 MHz (RML-4), 6.3 MHz (RML-6)

$(S/N)_{IN}$ = 38 dB (RML-4), $(S/N)_{IN}$ = 53 dB (RML-6)

NF = 14 dB (RML-4), 10 dB (RML-6)

Fade Margin (worst case processing gain)

18 dB - RML-4

33 dB - RML-6

No Preemphasis

Path Length 30 miles RML-4, 6

- o KEY FACTOR

RML-4, 6 (Major Equipment Types)

Manual Switching (RML-4)

Frequency Diversity (RML-6)

New RML Installations

TABLE 15

RML-4 PROCESSING GAIN VALUES

INFORMATION TYPE	CHANNEL NUMBER	PROCESSING GAIN (dB)
Beacon	1	1.3
MTI Video	2	-7.6
Normal Video	2	5.0
Voice and Control	3	42

$$S_{IN} = N_{IN} + (S/N)_{IN} \quad (7\text{-}1A)$$

$$= -174 \text{ dBm} + NF \text{ (dB)} + 10 \log BW + (S/N)_{IN} \quad (7\text{-}1B)$$

$$= -174 \text{ dBm} + 14 \text{ dB} + 10 \log 15 \text{ MHz} + 38 \text{ dB}$$

$$= -174 + 14 + 71.7 + 38$$

$$= -50 \text{ dBm}$$

A proposed receiver front-end improvement kit could change the noise figure from 14 dB to approximately 10 dB. This would result in a 4 dB increased fade margin and a small decrease in the allowable flight time values given in Table 21.

The noise processing gain for the RML-6 link is summarized in Table 16.[26] These values are derived in detail in the FAA reference and are obtained in a similar manner to the RML-4 values.[1] The RML-6 minimum output (S/I) is also 12 dB for the critical links.

The RML-6 median input signal level is given by:

$$S_{IN} = -174 \text{ dBm} + 10 \text{ dB} + 10 \log (45 \text{ MHz}) + 53 \text{ dB} \quad (7\text{-}2)$$

$$= -174 \text{ dBm} + 10 + 77 \text{ dB} + 53 \text{ dB}$$

$$= -34 \text{ dBm}$$

GROUND TESTS

General - The object of the ground test was to measure, in a closed link system configuration, basic receiver characteristics required for the interference analysis and the SHF SATCOM airborne test. The ground tests were first conducted on 18-24 November 1974[9] and repeated on 14-23 May 1975 along with the airborne tests.

The details of the November tests are described in Reference 9 and will not be repeated in this report.

TABLE 16

RML-6 PROCESSING GAIN VALUES

INFORMATION TYPE	PROCESSING GAIN (dB)
Beacon	-5.2
Normal Video	-7.7
MTI Video	-7.7
Azimuth Pulses	-8.2
Service and Voice Channels	15.8
60 Voice Channels	6

The basic block diagram used in the test is shown in Figures 43, 44 and 45. Figure 43 indicates the test configuration used for Channels 1, 2 or 3 of the RML-4. In this configuration, the signal to be interfered with has baseband slot filters introduced one or more hops before the site at which the interference is introduced. At Site 2, the input interference was measured along with the slot noise output interference power. The AGC voltage was used to monitor the input desired signal level. The output desired signal level was obtained from calibration measurements in which the proper level of the desired signal was introduced at Site 1 and measured at the output of Site 2. Sufficient information was therefore available to obtain the relationship between the input and output signal-to-interference power ratio. In addition to this relationship, subjective performance degradation to the output video display (Channel 1 or 2) and error probability evaluation of the narrow band digital signal (Channel 3) was measured at Site 3 for the RML-4. For Channel 1 (Beacon) and Channel 2 (MTI/Normal), the output display (scan converted video) at Site 3 was subjectively evaluated to determine the appropriate degradation thresholds. For Channel 3 the output signal was routed to a FAA computer and evaluated for message errors and loss of messages. Figure 44 indicates the test configuration used for the RML-6. The basic difference between this and the RML-4 is that the subjective performance degradation measurements were made at Site 2. For the case of the RML-6 system, the PPI output was subjectively evaluated for the MTI/Normal and Beacon configuration. The Channel 5 test (Figure 45) was different from the previous tests only in that the microwave path in the opposite direction was being used and consequently the desired signal was introduced at Site 3. The output signal

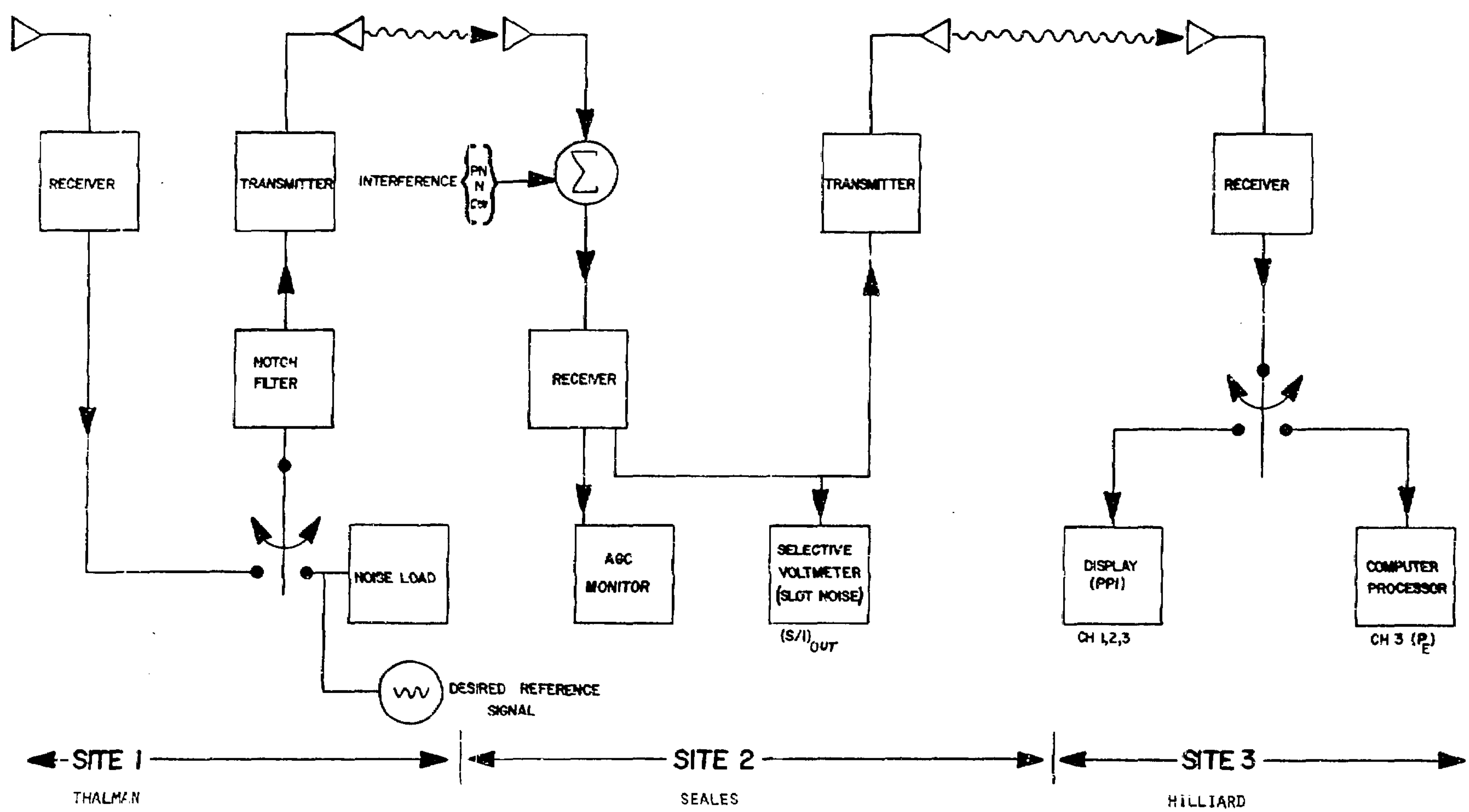


Figure 43 RML-4 Channel 1, 2 and 3 Ground Test Setup

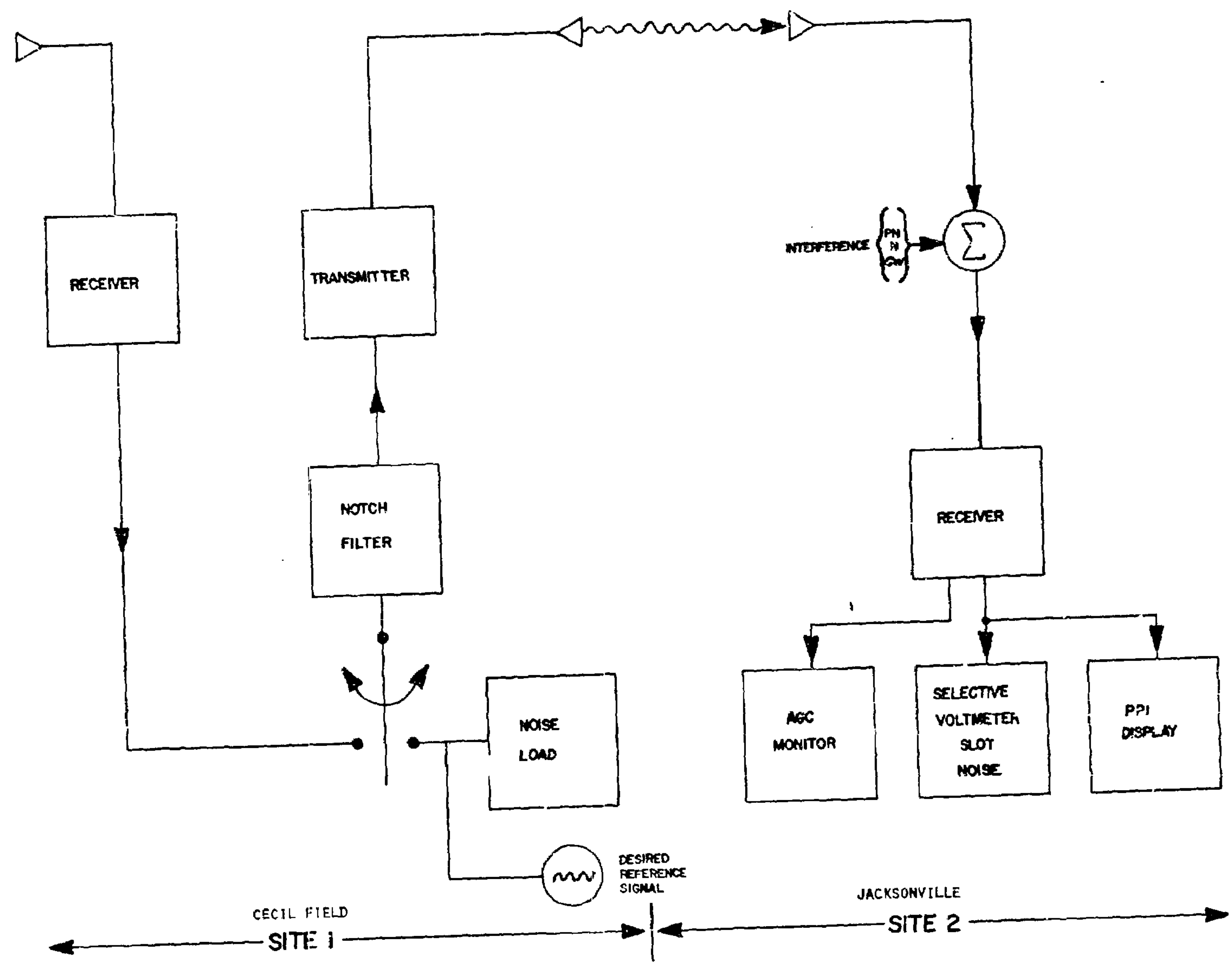


FIGURE 44 RML-6 GROUND TEST SETUP

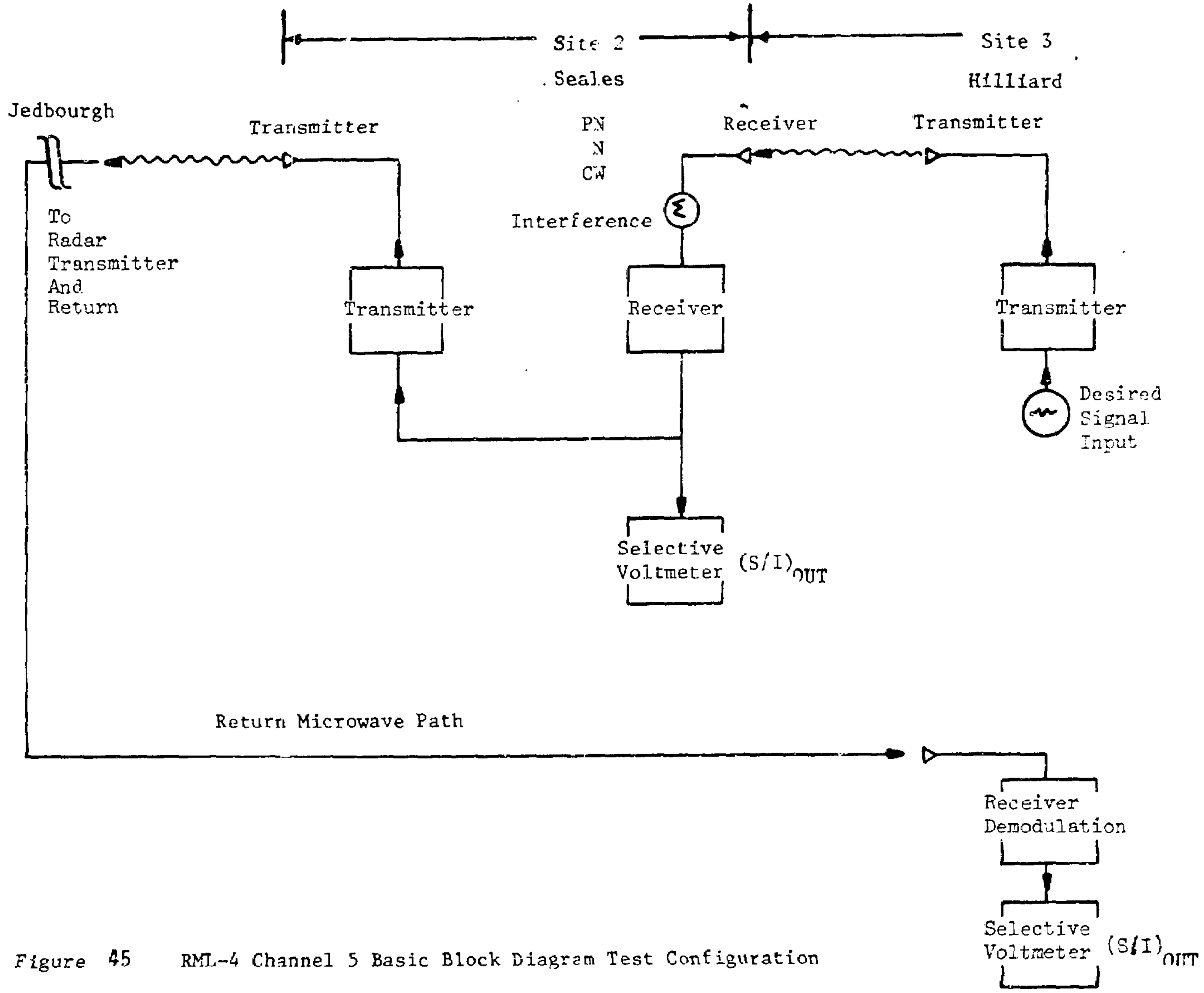


Figure 45 RML-4 Channel 5 Basic Block Diagram Test Configuration

was monitored at both Site 2 and Site 3 after travelling the entire microwave back and forward path for the Channel 5 test.

The receiver characteristics measured in the ground tests for the RML-4 and RML-6 links were:

1. AGC
2. Quieting Slot Noise
3. Slot interference power for a Noise loaded baseband (PN, N or CW interference)
4. Slot interference power for Regular FAA loaded baseband; Channels 1, 2, 3 and 5 (PN, N or CW interference).
5. Interference thresholds for MTI/Normal and Beacon of the RML-4 and RML-6.
6. Closed System S/I Degradation Criteria

The following describes the results of these measurements.

AGC - The AGC characteristics of the RML-4 and RML-6 receiver are shown in Figure 46. The characteristics were measured numerous times during two separate measurement periods. They are shown both for the measurements obtained by the SHF SATCOM test crew and typical measurements obtained by the FAA at another time. The test crew measurements had a high degree of repeatability and agreement with the FAA measurements. The HP 3403 AGC curves were used to calibrate the desired input signal level in all of the subsequent slot noise interference tests. The RML-4 and RML-6 curves were used in the airborne antenna tests to identify the received CW signal power level when the FAA microwave signal was turned off.

Quieting Slot Noise - The quieting slot noise curves for the RML-4 and RML-6 receiver are shown in Figures 47 and 48 respectively. These curves were obtained with an unmodulated desired signal (CW) and basically measure the noise in a channel that is ideally directly proportional to frequency

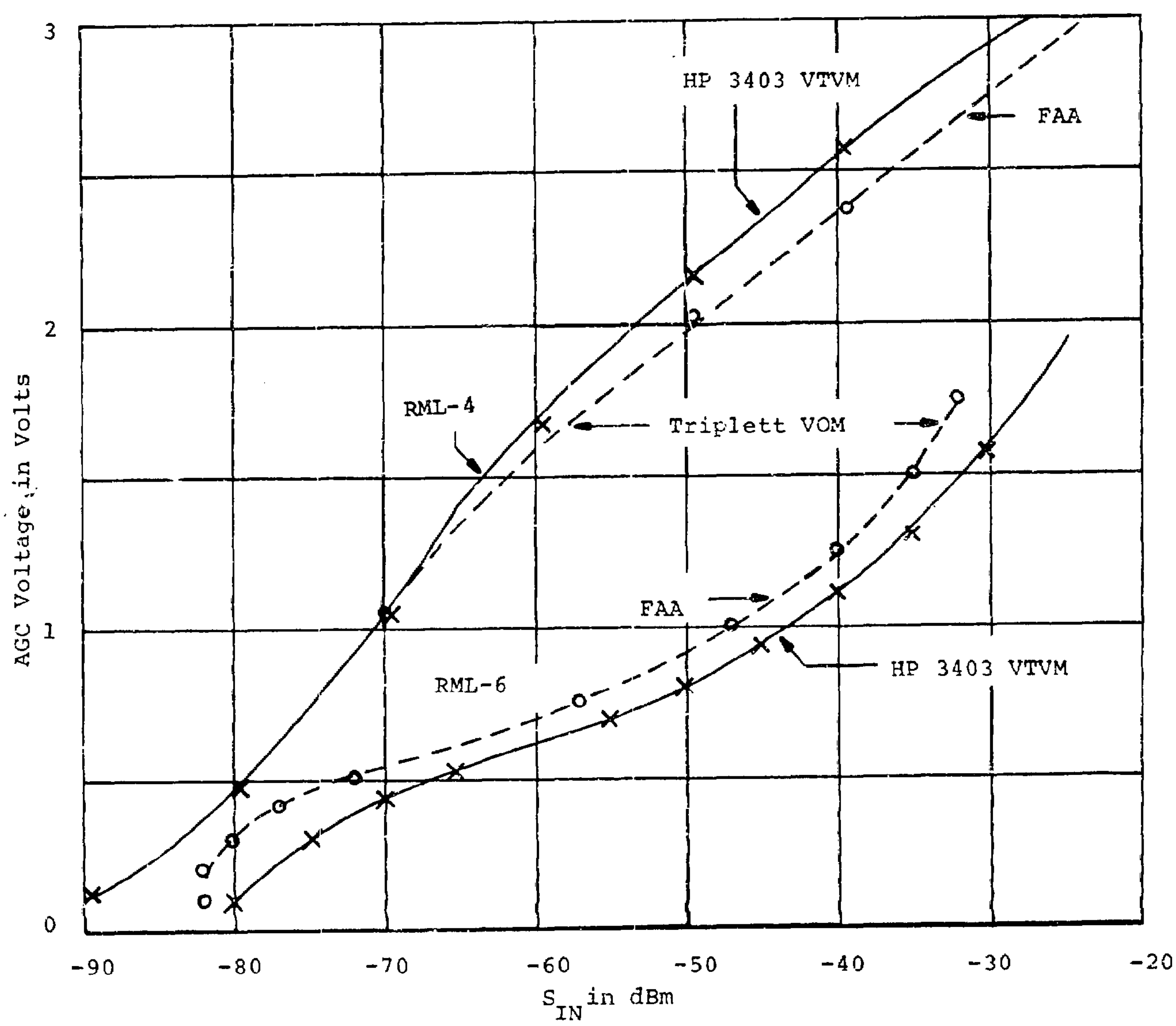


Figure 46 RML-4 and RML-6 AGC Characteristics

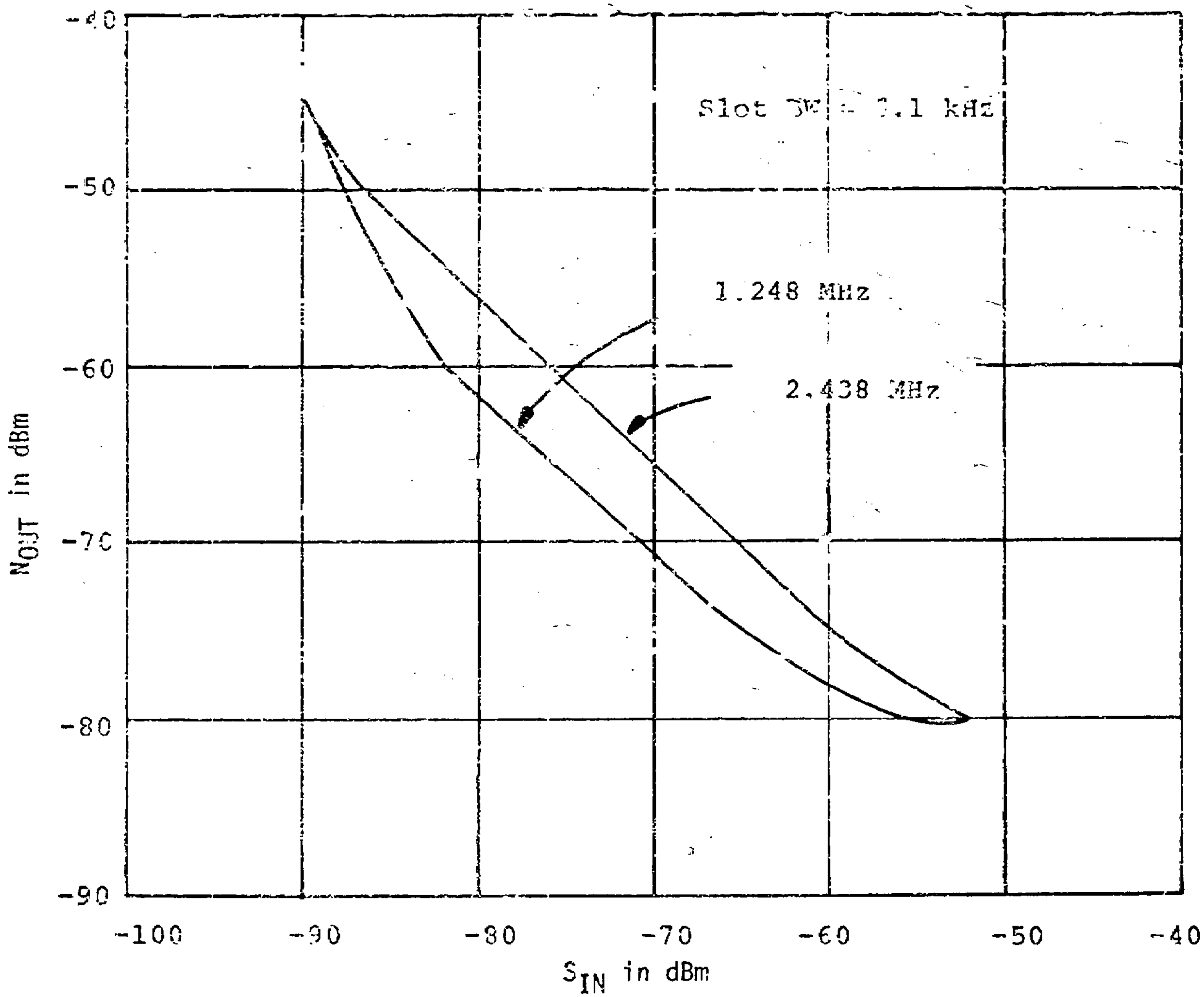


FIGURE 47 RML-4 CW SLOT NOISE QUIETING

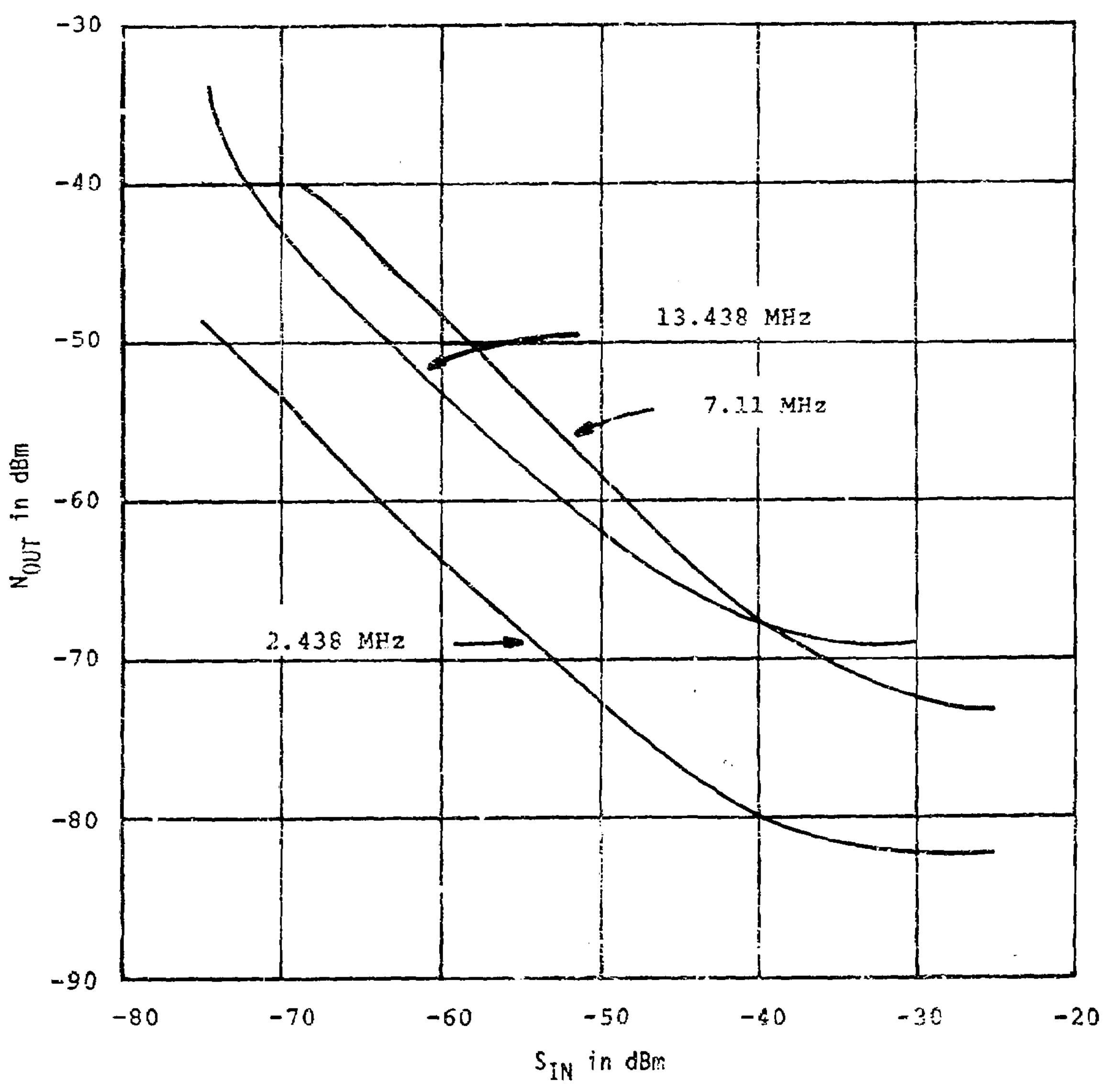


FIGURE 48 RML-6 CW SLOT NOISE QUIETING

squared (f^2) and inversely proportional to the CW carrier level. For these measurements, it was specified that the receiver front end noise level was -88 dBm for the RML-4 and -87 dBm for the RML-6 receiver respectively. Consequently, instead of the input CW carrier level, the input signal-to-noise ratio was plotted. Repeated measurements of these curves were made during two separate periods. The curves show slot noise as a function of desired input signal power. The slot noise filter characteristics were previously discussed and are shown in Figure 13. The curves with a straight 1:1 slope indicate the linear operating region of a good receiver. If these curves are not linear over a large portion of their operating region, the interference slot noise measurements (these will be described in the next section) would also not be linear. This would increase the error in subsequent interference measurements. The curves shown in Figures 47 and 48 are reasonably linear and, therefore, indicate good operating receivers. The curves indicate non-linear operation for very weak and strong desired signal levels which is normal receiver operation (but not ideally desired).

Slot Interference Power for a Noise Loaded Baseband - The most important interference measurements made for the airborne SHF SATCOM system interference tests are the slot noise measurements which indicate the degradation of a receiver output channel as a function of the input interference power. Without these measurements, it would not be possible, during the flight test measurement, to know the signal strength of the undesired signal source. This is because the desired FM microwave signal and the undesired signal have overlapping spectrums and cannot be separated with a spectrum analyzer at the receiver input. This type of information is not specifically required

for the closed system tests since the desired and undesired signal power can be measured directly at the output of the respective signal generators or input to the receiver.

The slot noise measurements or the measurements of the power in a particular baseband frequency slot can be obtained with a fully loaded or a lightly loaded baseband. If a multiple channel FM system uses most of its channels, the baseband loading can be simulated by loading the baseband with noise. The FAA RML-4 channels 1 and 2 are loaded with analog data. Channel 3 of the RML-4 and the RML-6 are loaded with combinations of digital and miscellaneous data as previously described. The loading of these channels is lighter than a typical multiple voice channel system. The RML-4 and 6 systems were tested both with a noise loaded baseband and a normal FAA load. The noise loading measurements were done so that the FAA measurements could be compared with any heavily loaded system (i.e., TVA, AEC and others). The FAA noise loaded RML-4 and 6 receiver measurements are shown in Figures 49 through 54 respectively. These are shown for three representation voice slots (70 kHz, 1.248 MHz and 2.438 MHz) and three types of interference (PN, Noise and CW). These curves and all subsequent curves are plotted as a function of the input signal-to-interference power ratio [$(S/I)_{IN}$]. The original measurements were taken with specific interference and desired signal levels. Since the microwave carrier signal level varies with fading and from one location and/or equipment type to another, the curves have been normalized as a function of the $(S/I)_{IN}$ ratio so that the results are directly applicable to all similar types of microwave terminals providing the desired signal level is known. The curves show good linearity for the upper voice slots for the PN and Noise interference. The lower 70 kHz slots shows the

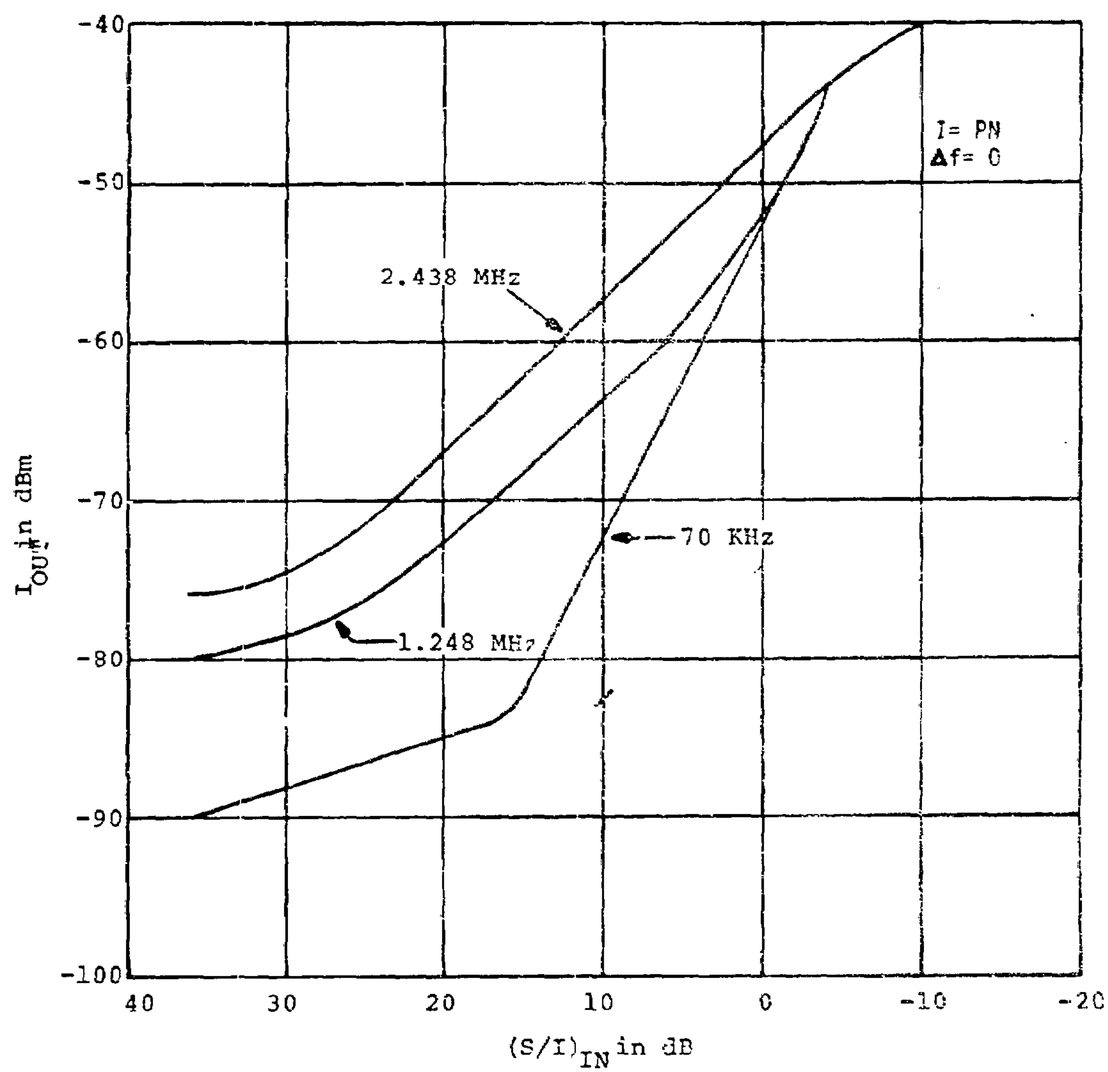


Figure 49 RML-4 Slot Noise (Noise Loaded) Versus PN Interference

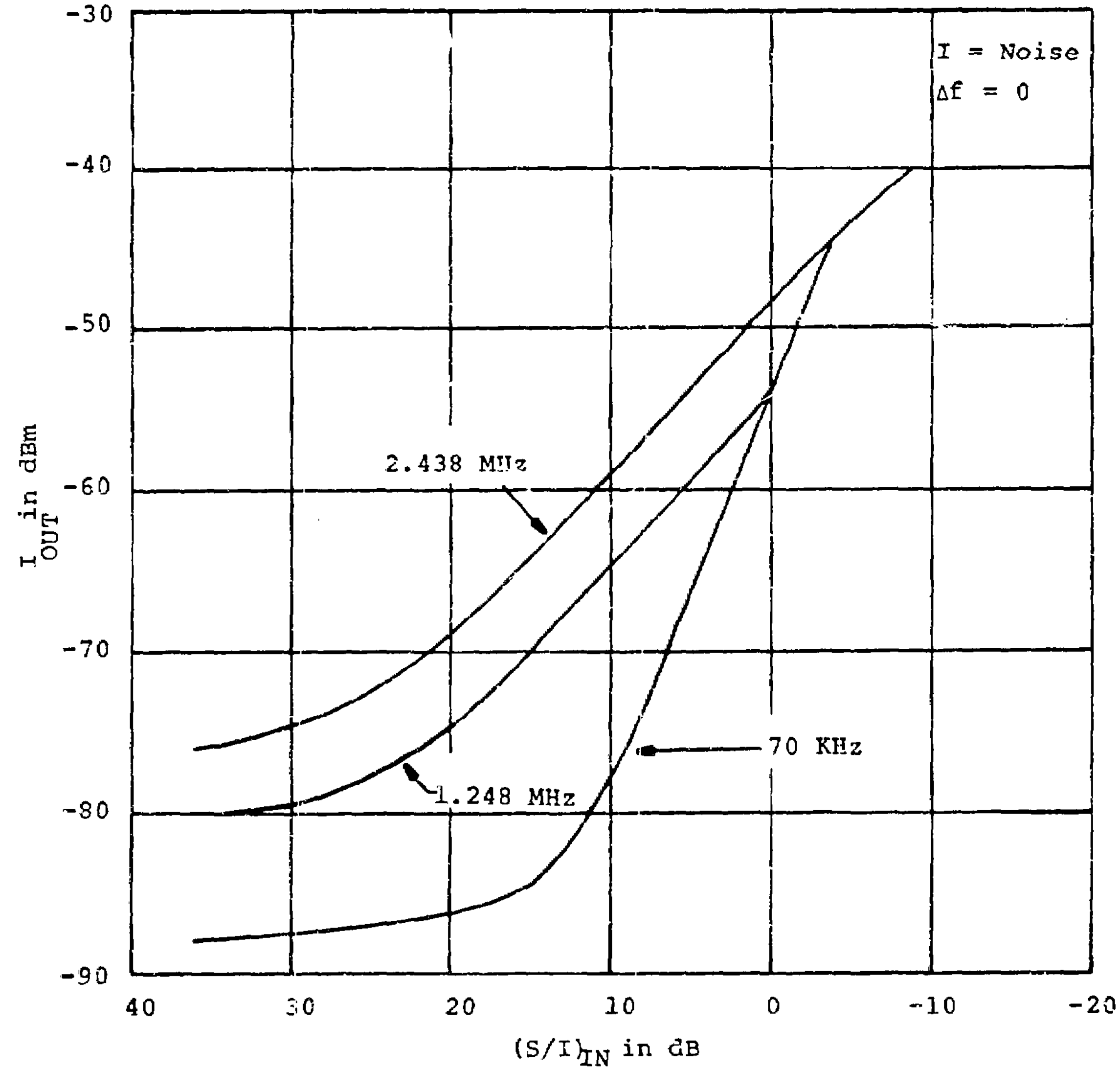


Figure 50 RML-4 Slot Noise (Noise Loaded) Versus Noise Interference

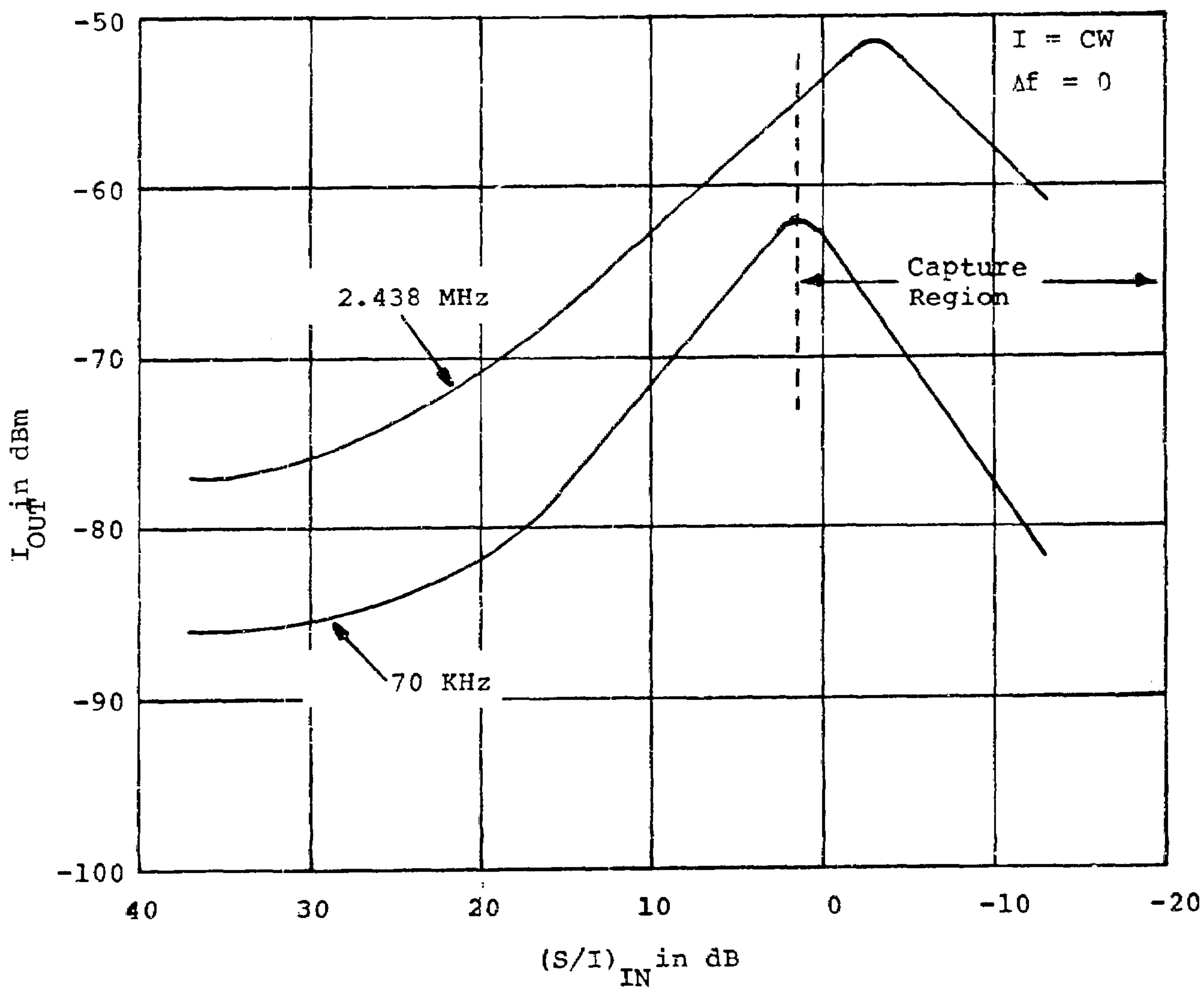


Figure 51 RML-4 Slot Noise (Noise Loaded) versus CW Interference

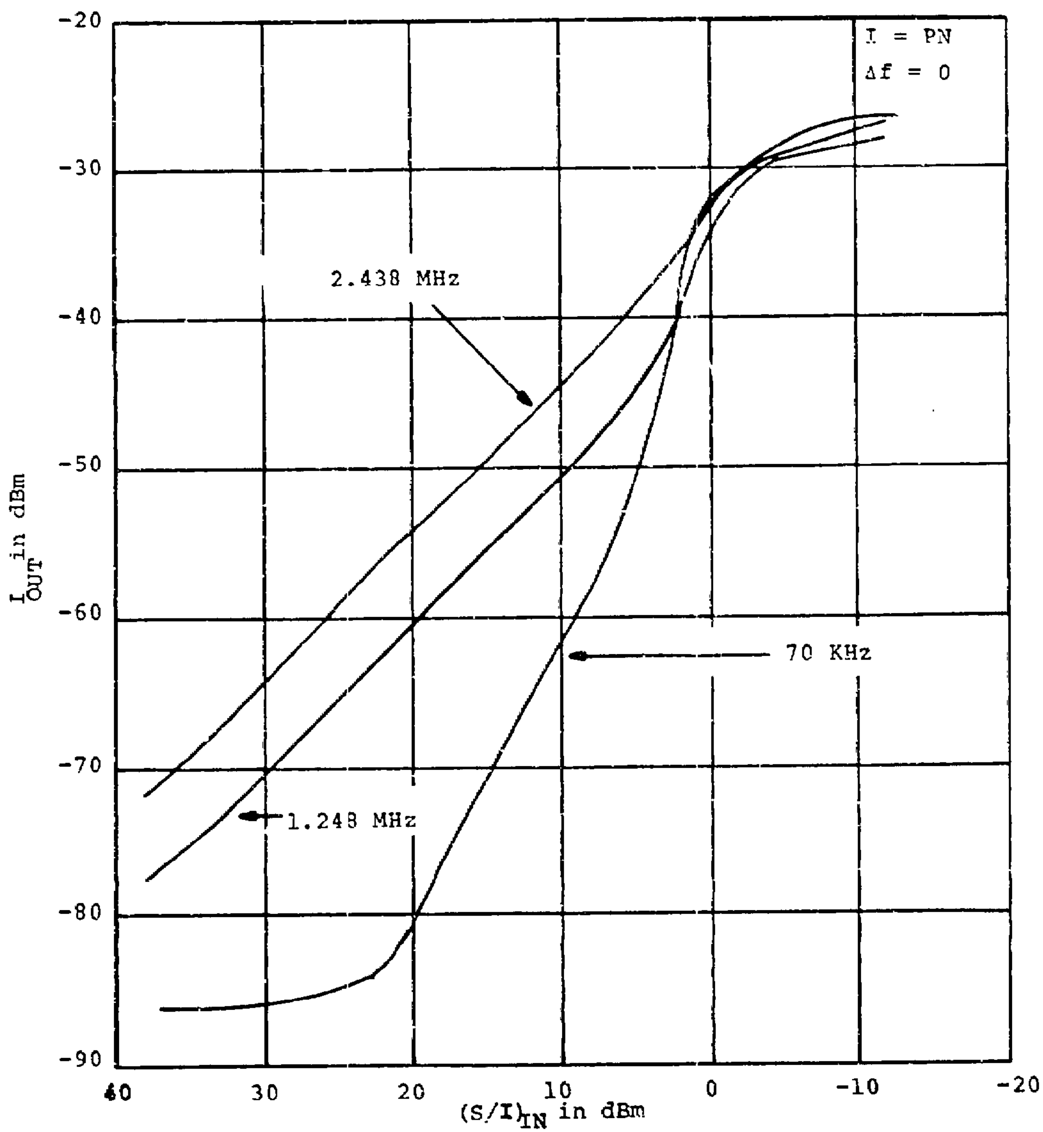


Figure 52 RML-6 Slot Noise (Noise Loaded) Versus PN Interference

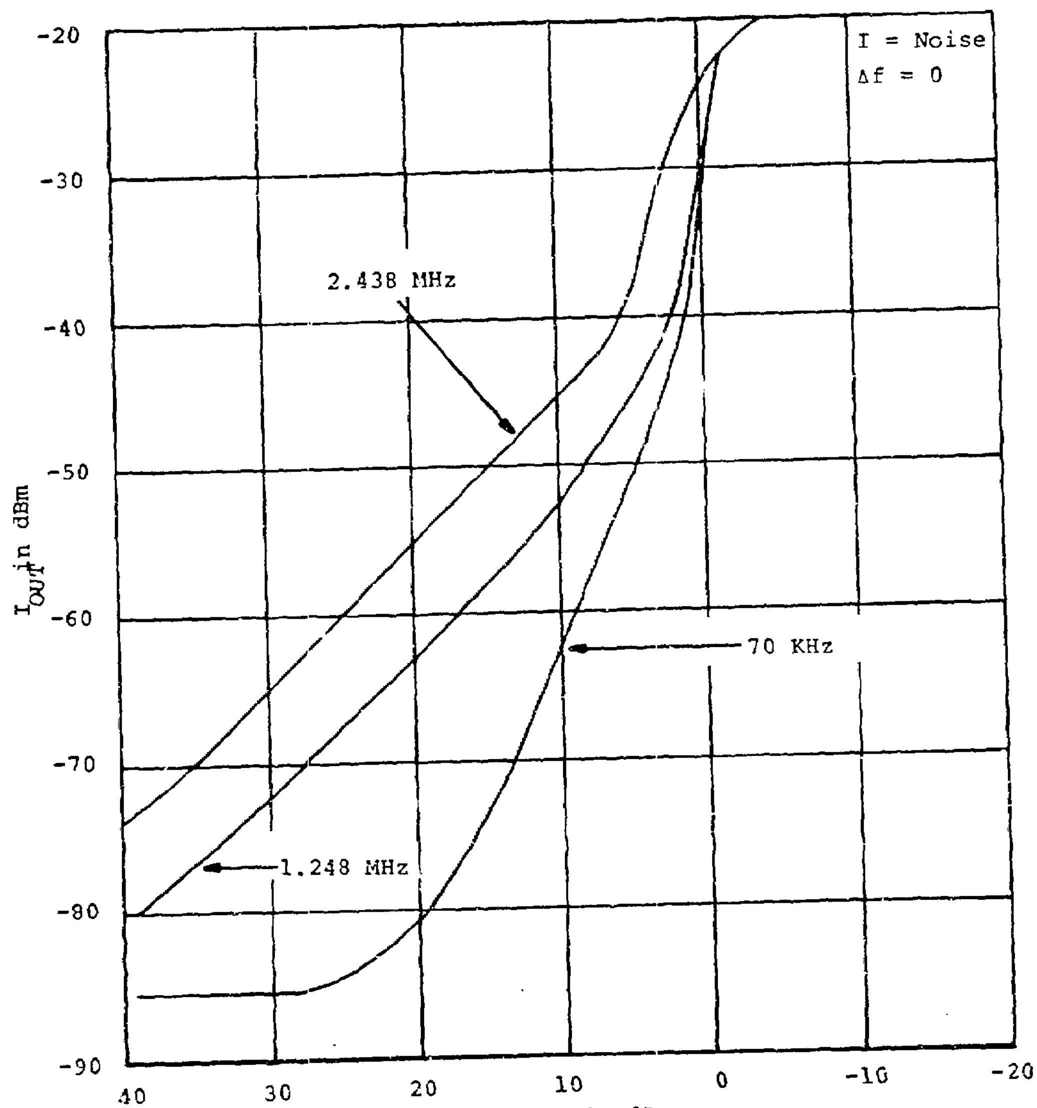


Figure 53 RML-6 Slot Noise (Noise Loaded) Versus Noise Interference

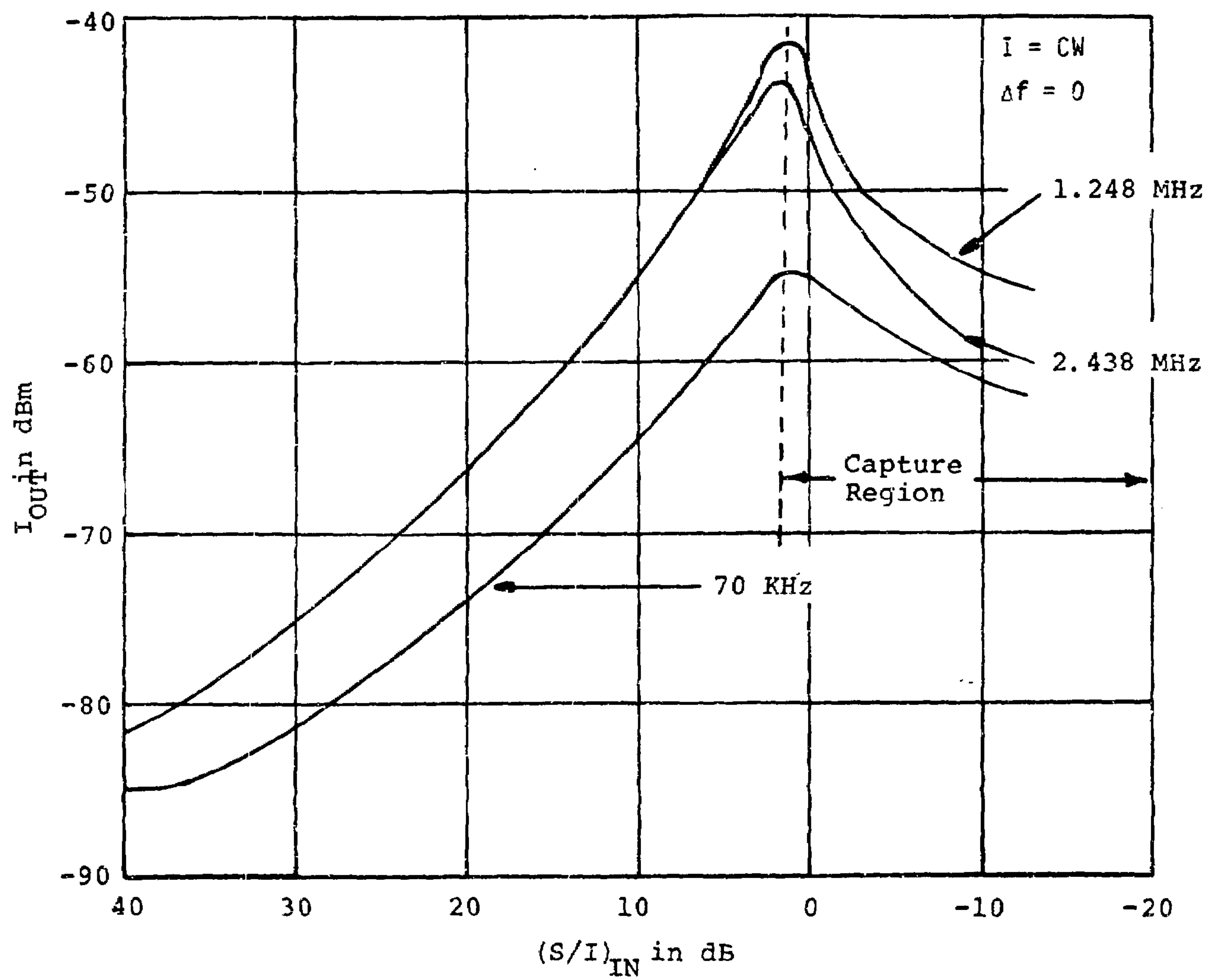


Figure 54 RML-6 Slot Noise (Noise Loaded) Versus CW Interference

typical lower channel non-linear effects due to intermodulation. The 2.438 MHz slot was used as the main monitor or reference channel. Therefore, no calibration problems were encountered since this is a reasonably linear channel.

The CW degradation curves shown in Figures 51 and 54 have a different shape than the PN or Noise curves for low signal-to-interference ratios. This difference is due to the hard capture of the receiver by the interference and AGC action.

Another technical area that was checked is the similarity between a true noise interfering signal (i.e., one that exhibits gaussian amplitude statistics) and the pseudo noise (PN) interfering signal that was being examined in the SHF SATCOM study. A comparison between the two types of interference is shown in Figures 55 and 56 for the RML-4 and RML-6 respectively. The figures show that the noise and the PN signal creates approximately the same level of receiver degradation. This in turn means that the noise processing gain analysis equations contained in the literature can be used to predict the degradation effect of the PN signal. It should be noted that there is a slight difference (1.5 dB) between the interference effect of the PN and the noise signal, which is due to the $(\sin x/x)^2$ roll off of the PN spectrum versus the flat gaussian noise spectrum. The PN components at 2.438 MHz is effectively higher than the flat noise component at this frequency because the total power of the $(\sin x/x)^2$ is averaged over the 40 MHz bandwidth. This normalization effectively raises the central portion of the spectrum and lowers the tails of the $(\sin x/x)^2$ spectrum which is shown in Figure 16.

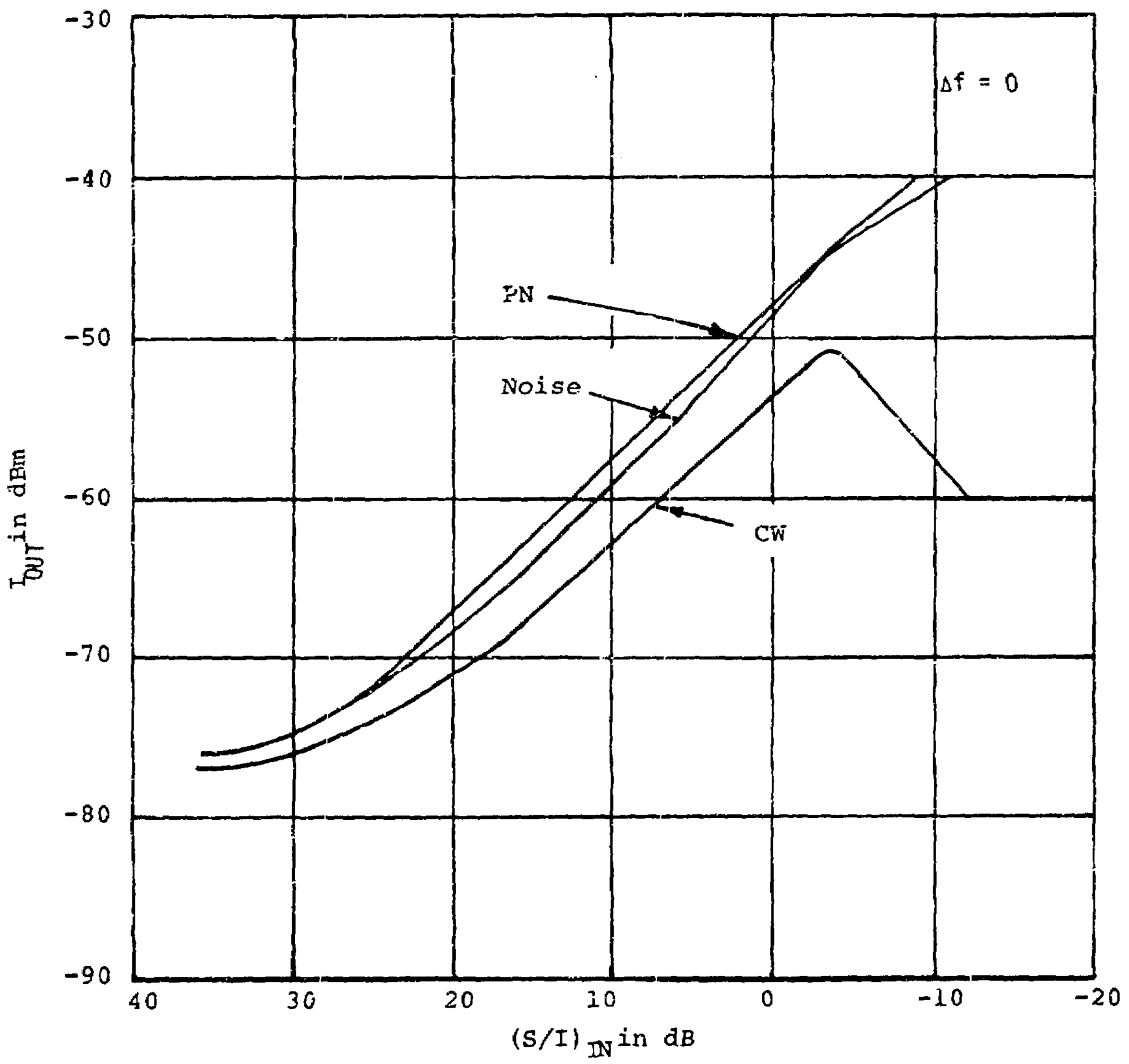


Figure 55 Comparison between PN, Noise and CW Interference to RML-4

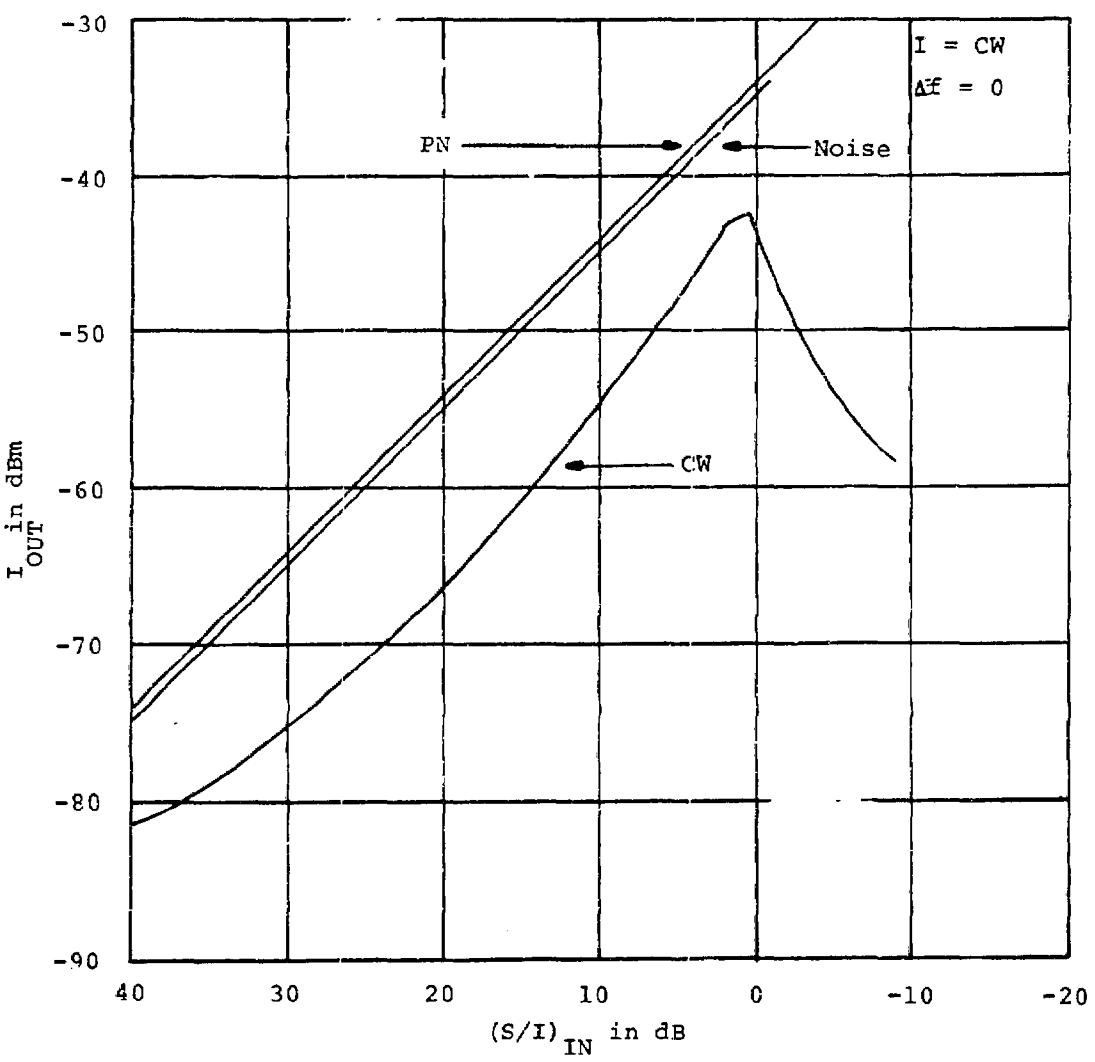


Figure 56 Comparison between PN, Noise and CW Interference to RML-6

Slot Interference Power for Standard FAA Loaded Baseband - The measurements described in this section are the same type as that described in the previous section except that the baseband signal consists of the standard FAA baseband modulation. The modulation loading is therefore very light relative to the 100% noise loading used in the previous measurements. The RML-4 and 6 curves are given in Figures 57 to 62 for PN, N and CW interference.

A comparison between these curves and those previously measured with noise loading shows that the PN and noise (N) curves are very similar. This then shows that the interference in the slot was mainly dependent upon the PN or N interference level and independent of the desired signal modulation. For the CW interference case, this is not true and the level of interference is dependent upon the desired modulation and the slot being measured. It is apparent from the measurements that in the lightly loaded case, there is little coupling of interference power to the 2.4 MHz slot channel (Figure 61 and 62) until the CW level approaches the desired signal or capture level. After this point, a combination of the capture mechanism and AGC action take over to make the curves reverse themselves.

Interference Thresholds for MTI/Normal and Beacon Channels of the RML-4 and RML-6 - Channel 1 of the RML-4 carries beacon information while Channel 2 carries normal radar and MTI information. The information is displayed as scan converted video which has the effect of retaining targets and or interference longer than they would on a normal PPI. The RML-6 carries both beacon and MTI/Normal information that is displayed on a PPI. In order to assess interference effects to these channels, it was necessary to subjectively evaluate performance degradation. In order to bracket the interference problem from minimum to maximum levels, it is necessary

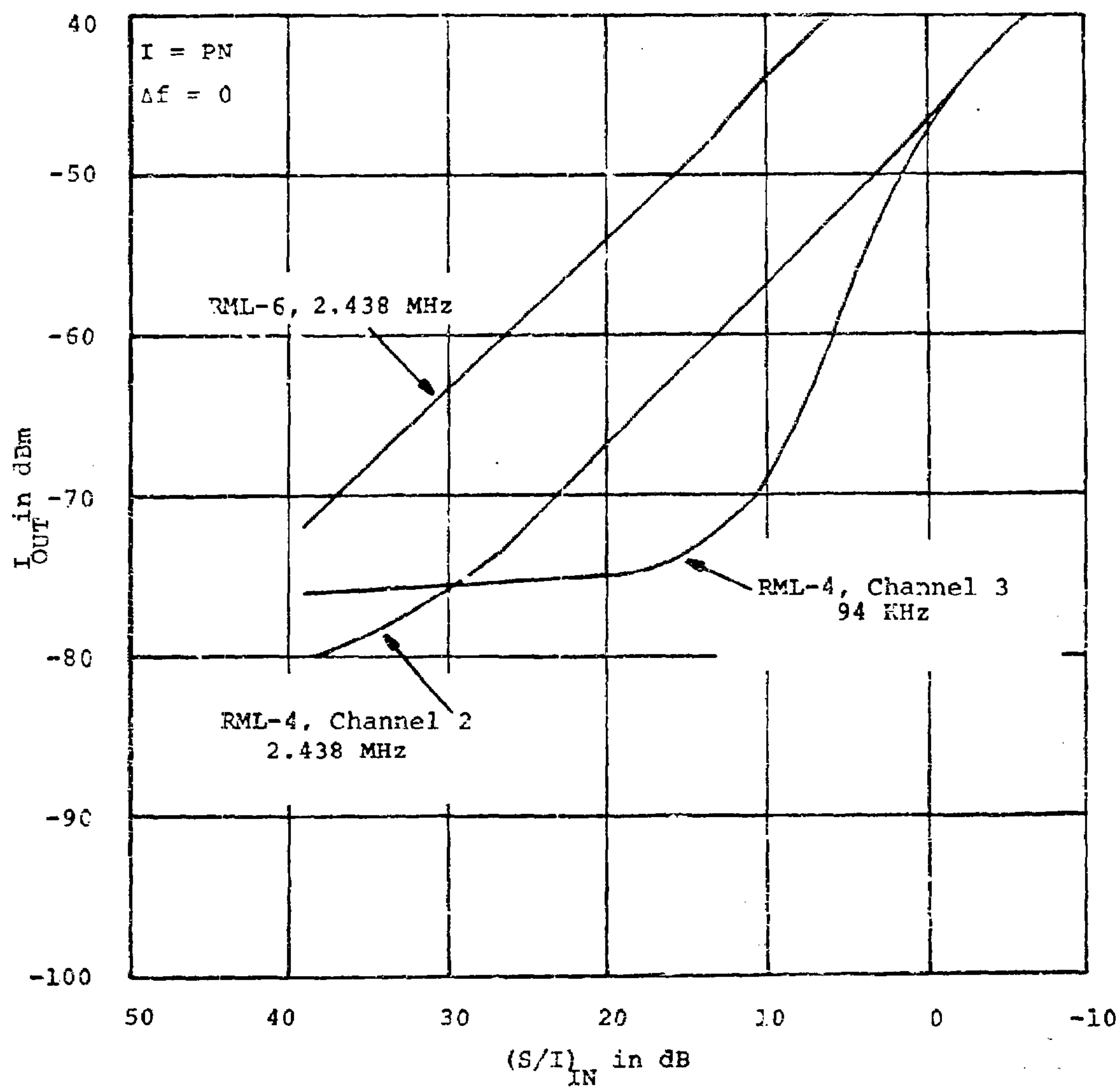


Figure 57 Comparison Between Slot Noise of RML-4 and RML-6 (Normal FAA Loading) For PN Interference

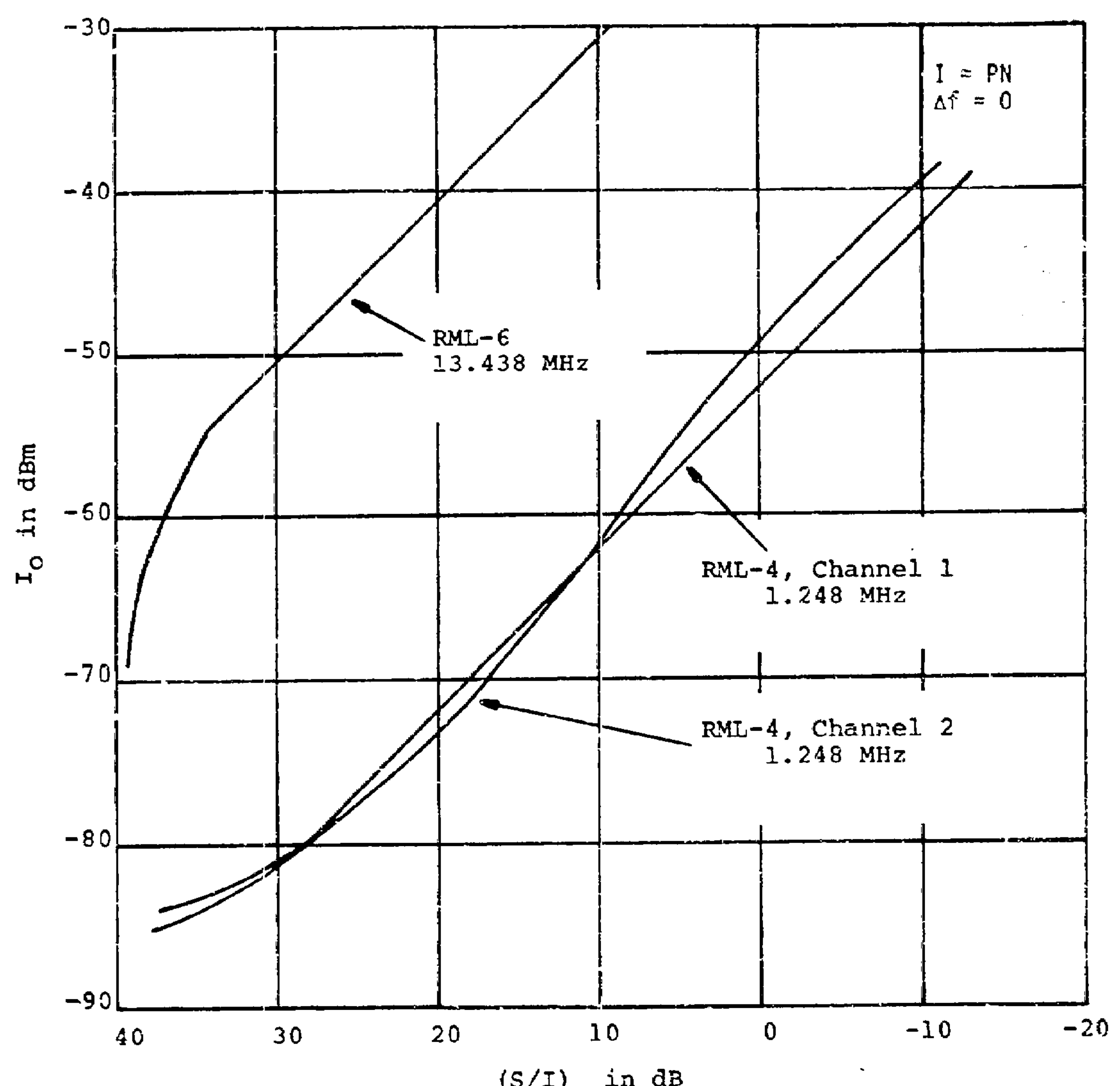


Figure 58 Comparison Between Slot Noise of RML-4 and RML-6 (Normal FAA Loading) For PN Interference

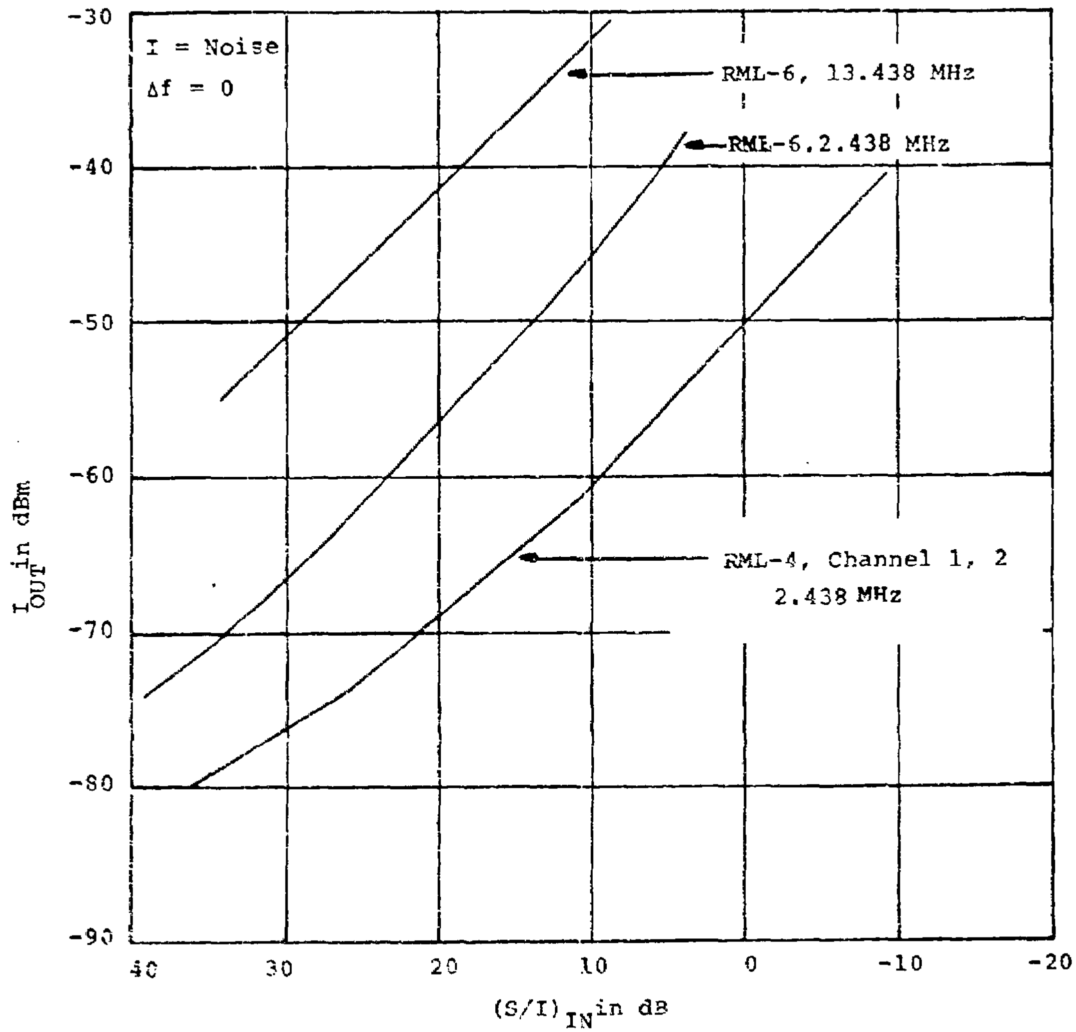


Figure 59 Comparison Between Slot Noise of RML-4 and RML-6 (Normal FAA Loading) For Noise Interference

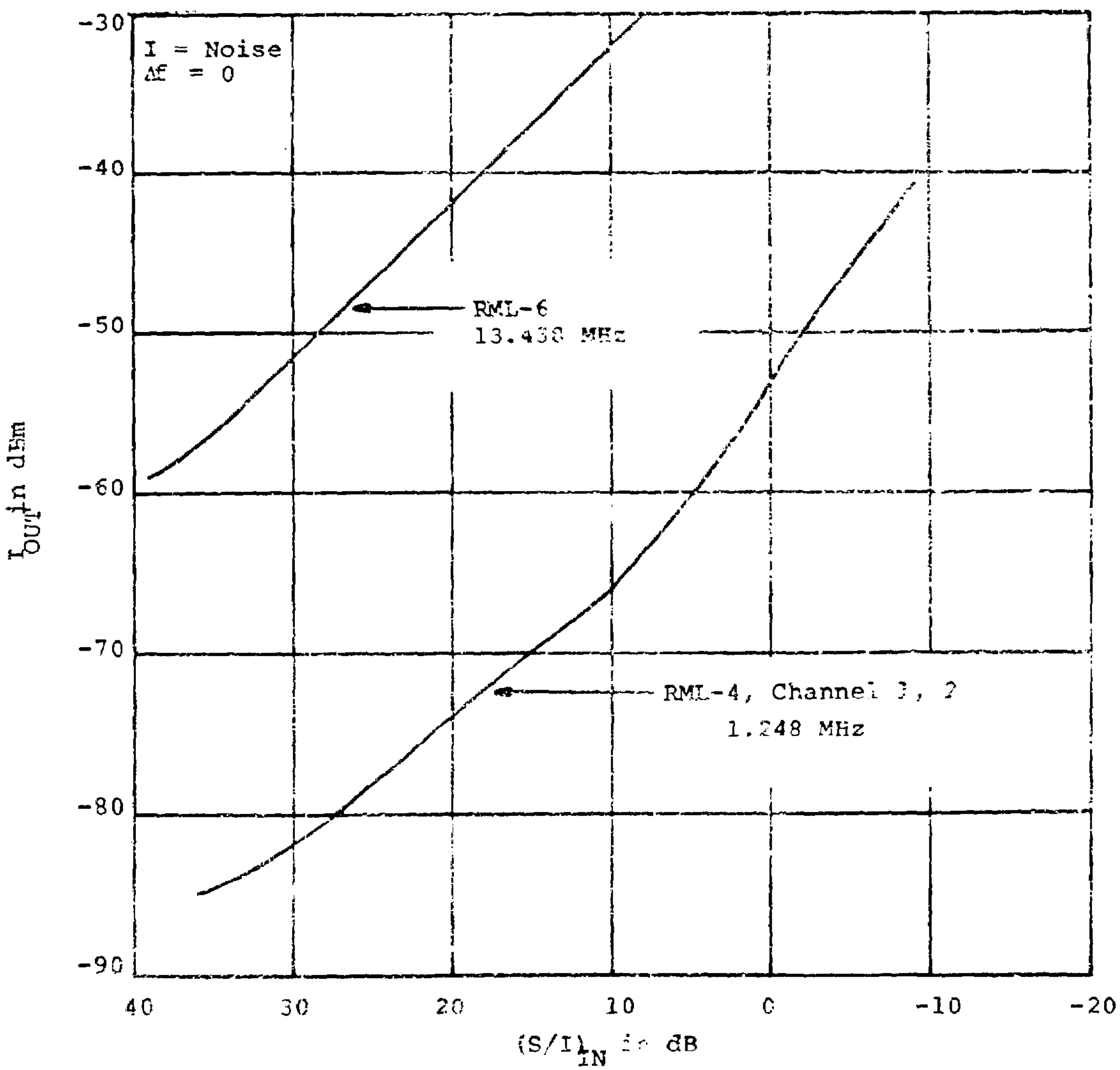


Figure 60 Comparison Between Slot Noise of RML-4 and RML-6 (Normal FAA Loading) for Noise Interference

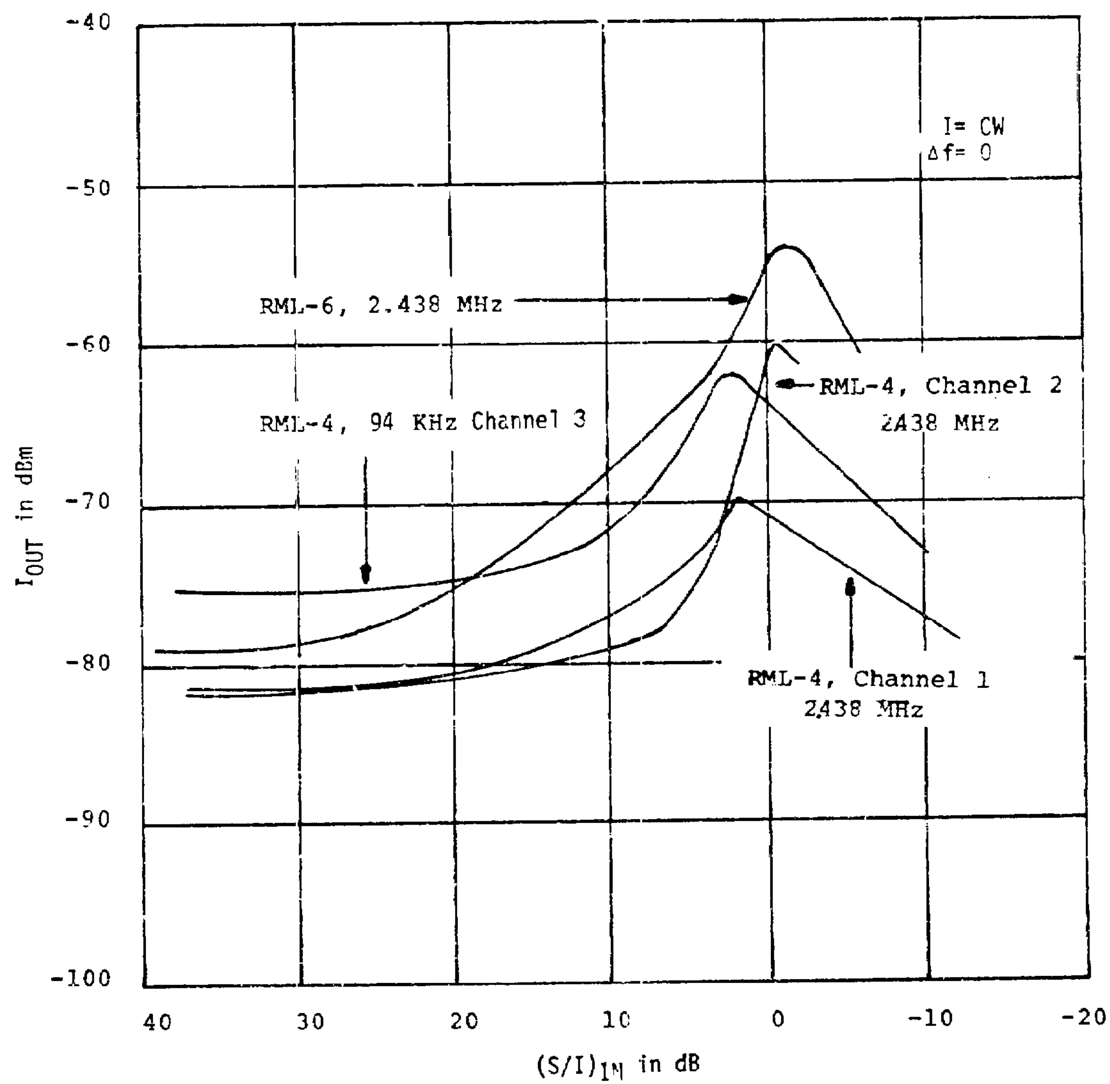


Figure 61 Comparison Between Slot Noise of RML-4 and RML-6 (Normal FAA Loading) for CW Interference

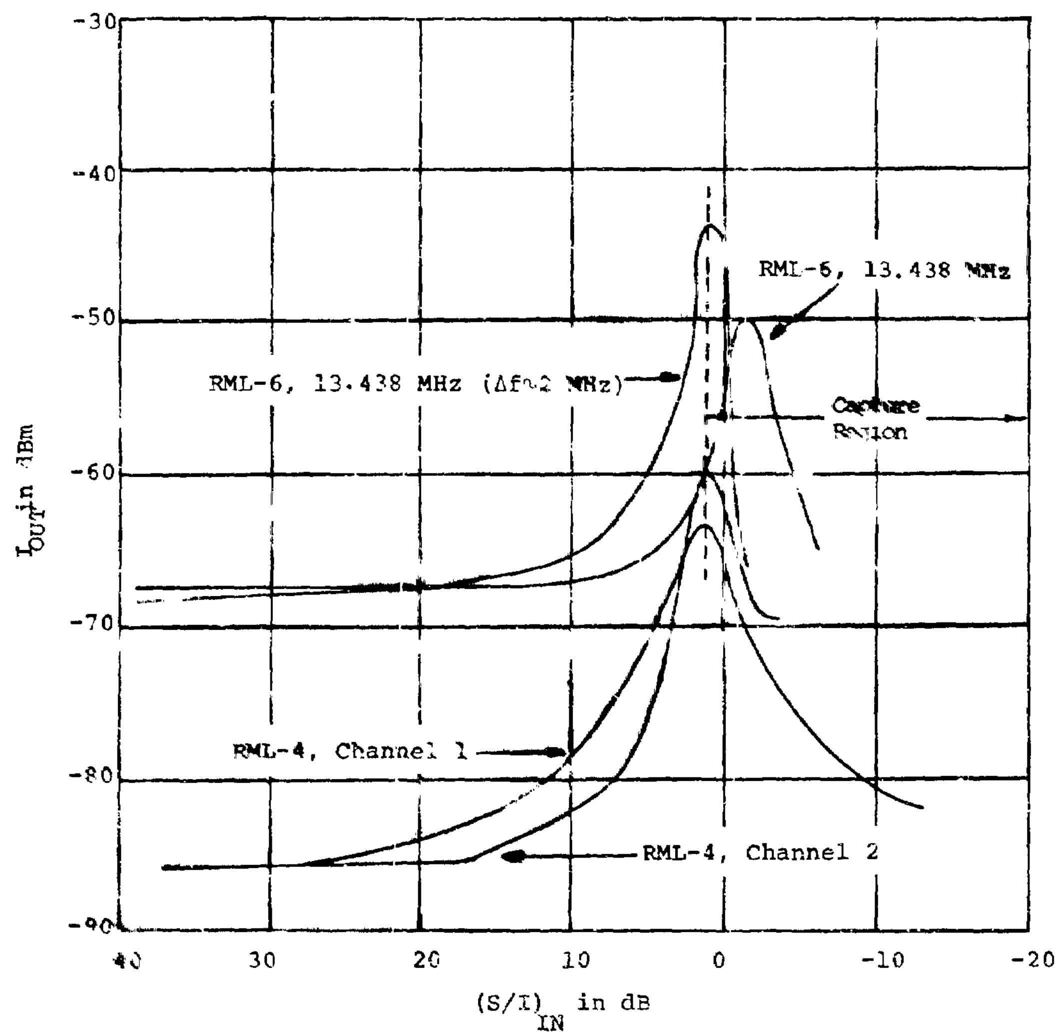


Figure 62 Comparison Between Slot Noise of RML-4 and RML-6 (Normal FAA Loading) for CW Interference

to measure the interference level at which interference is first observed [(i.e., a Minimum Interference threshold (MINIT)] and the level at which all useful display information is lost [(i.e., a Maximum Interference threshold (MAXIT)]. The reason for measuring both thresholds is that there is an uncertainty associated with the subjective measurement process and this gives an additional indication of the possible inaccuracy of the threshold values. If the thresholds are only separated by a few dB (which they are in the beacon and MTI/Normal case) there is a small error if one has evaluated a MINIT instead of a MAXIT level.

The MINIT thresholds on the MTI/Normal presentation were obtained by noting an increase in the Normal noise which approximately doubled with the introduction of the PN or N signal. The threshold was variable to ± 1 dB for different observers which was more related to the average intensity of interference than the detection of the interference. This corresponded to a light "dusting" of the screen.

The MAXIT threshold was obtained by increasing the interference until the noiselike undesired signal filled the PPI to a moderate intensity. This corresponds to approximately a 5 dB increase in interference level from the MINIT level. As the level was increased beyond this point, the intensity of interference became extremely heavy and targets were lost.

The next level that was recorded (for the RML-6) was the loss of synchronization. This was the only non-subjective value recorded. It should be noted that the presentation at this point was already unacceptable since most of the targets were gone. The (S/I) values are given in the summary Degradation Criteria Section.

Channel 3 Interference Tests - The 24 voice/data channels (312-552 kHz) used for narrow band digital data and the synchro information, were determined by the FAA to be the critical information carried by Channel 3. The digital data channel was evaluated with two different message error check programs. The programs were the Operational Analysis Program and the CD Quality Precheck Program (Reference 27). Table 17 summarizes the results of the ground tests using both programs for PN, N and CW interference. The "Average Messages" column identifies the number of target returns processed during the fixed time interval of the error check program. Both programs record different types of message errors which can result in more than one error per message being recorded. Since the types of error cannot be separated, only a column labeled total errors has been recorded and lists the sum of the individual group errors recorded by the programs. This number should be used to separate the point where no errors are present from a point at which errors start to be received. In addition to using the total errors as a threshold indicator, the average message rate is also an indicator of when messages are being lost due to desensitization. Figure 63 shows what happened to the total error count and messages received for a typical PN interference case.

Examination of Table 17 indicates an average MINIT threshold of 10 dB for the PN case and 9 dB for the noise case. The MAXIT is approximately 9 dB for the PN and 8 dB for the Noise case. The small difference between these values is caused by the rapid increase in lost messages. The lost messages are caused by the combined effect of FM capture, AGC and signal desensitization which occur simultaneously and make the change from no errors to large errors occur within a few dB.

TABLE 17

CHANNEL 3 CLOSED SYSTEM DEGRADATION TESTS

AVERAGE MESSAGES	TOTAL ERRORS	INT. TYPE	I_{IN}	S_{IN}	RF INPUT $(S/I)_{IN}$	ERROR PROGRAM	IF OUTPUT INBAND $(S/I)_{IN}$	COMMENTS
759	0	PN	-55	-46	9	OAP[1]	14	Threshold
642	125	PN	-52	-46	6	"	11	Some desensitization
196	174	PN	-49	-46	3	"	8	Heavy desensitization
777	0	N	-55	-47	8	"	13	Threshold
730	20	N	-52	-47	5	"	10	
256	206	N	-49	-47	4	"	9	
914	0	CW	-55	-47	8	CD Q.P[2]	8	
0	0	CW	-50	-47	3	"	3	TOTAL Desensitization
150	0	PN	-57	-46	11	"	16	Below Threshold[3]
159	6	PN	-55	-46	9	"	14	Above Threshold
157	563	PN	-53	-46	7	"	12	
150	0	N	-55	-46	9	"	14	Threshold
152	402	N	-53	-46	7	"	12	
17	971	N	-51	-46	5	"	10	Heavy desensitization

[1]Operational Analysis Program - Interval of check = 1 minute

[2]CD Quality Precheck - Interval of check = 12 seconds

[3]10 dB estimated threshold

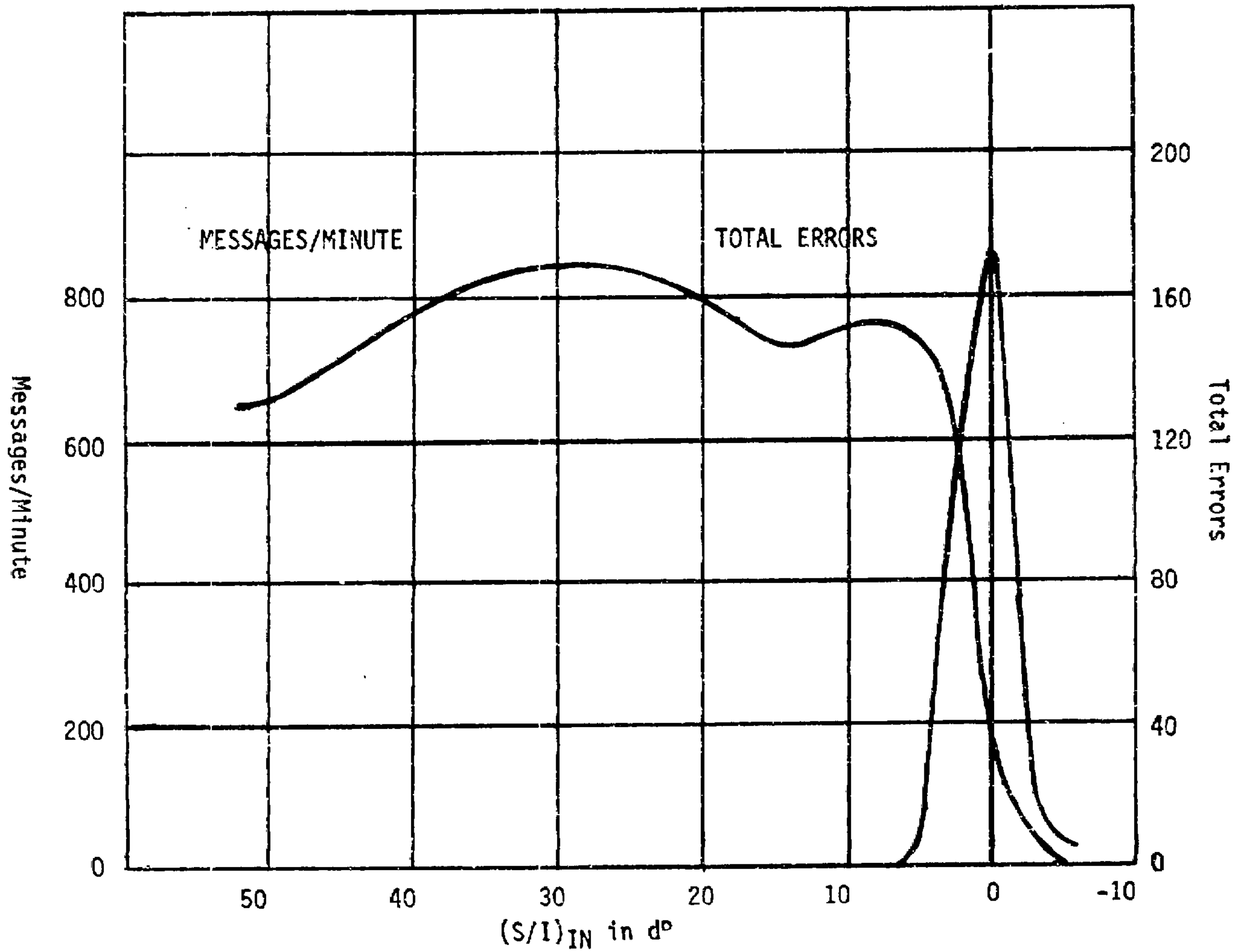


FIGURE 63 EFFECT OF PN JAMMING ON CHANNEL 3 DIGITAL DATA

Channel 3 also carries the synchronization (synchro) information for the MTI/Normal channels. Since this channel will become inoperative if the synchro signal is lost, it is also necessary to determine the susceptibility level of this channel and compare the interference level with Channel 2. The measurements were made by increasing the interference level to Channel 3 and noting when the MTI/Normal display has a loss of synchro information and the sweep stops. This level was measured as 7 dB for PN and 6 dB for Noise which indicates that the Channel 3 digital information or Channel 2 MTI/Normal information is more susceptible to interference than the Channel 3 synchro information.

Channel 5 Interference Tests - The 24 voice/data channels and the 308 kHz pilot were identified by the FAA to be the most important information signals carried by the Channel 5 return link. The output desired signal to undesired interference power was measured for a typical command and control voice channel (Channel 3) and is shown in Figure 64. These curves show both the PN and Noise results measured at both Seales (the site where the interference was being injected) and Hilliard (the end of the round trip, Hilliard, Florida to Jedburg, South Carolina, microwave path for Channel 5). These measurements show that both the PN and N were similar and that there was very little additional noise and distortion added to the interference after the signal had been relayed from Seales to Hilliard through the radar site. The voice channel communication was maintained until a (S/I) of approximately 0 dB was reached. However, desensitization of the desired signal began at approximately 10 dB which is indicated by the change in slope of the transfer curves. The 10 dB input S/I ratio corresponds to an output ratio of 30 dB which is often

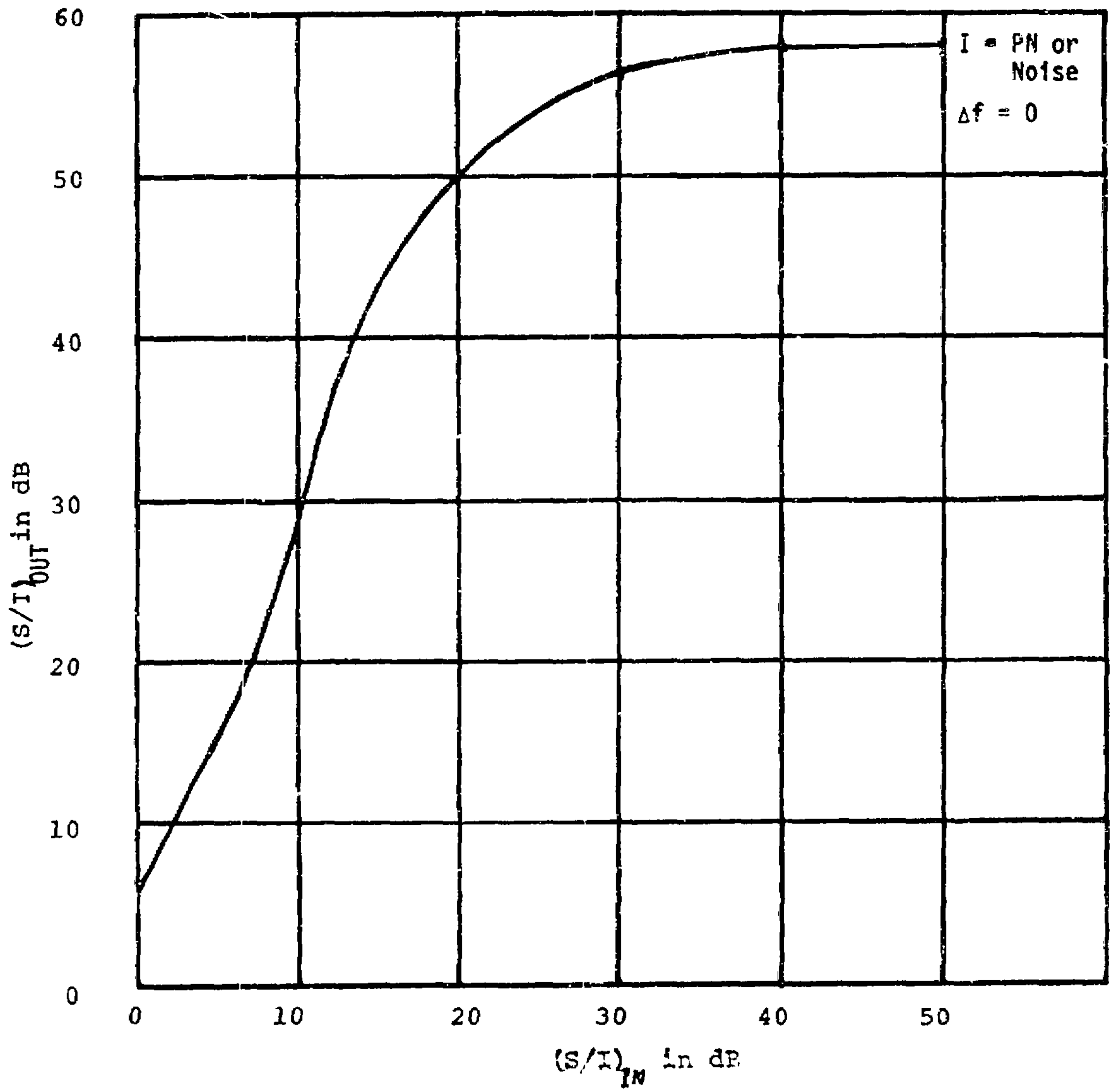


Figure 64 Channel 5, Command and Control Channel Slot Noise versus PN or Noise Interference

used as a minimum high quality criterion for voice communications. The DCA tactical performance standard, as one example, is 30 dB. This level has consequently been used as the threshold level of degradation in quality (not a MINIT criterion) for Channel 5.

In addition to the command and control channels, the pilot was also examined for desensitization and is shown in Figure 65. If a 6 dB desensitization of the pilot tone is caused by the interference, the pilot tone is lost. This loss would, in turn, cause all channels to be improperly demodulated if the system went through sufficient frequency drift. However, the stability of these systems is sufficient that this drift would probably not occur and consequently loss of the pilot tone will cause no system degradation. Figure 65 indicates that a negligible 1/2 dB desensitization is created at an input S/I of 10 dB. This agrees with the criteria chosen for the command and control channels and has also been chosen for the pilot degradation criteria.

<u>Closed System S/I Degradation Criteria</u> - The previous transfer function measurements described the relationship between input and output power ratios without drawing specific conclusions about what level of power is considered acceptable or unacceptable. These results will be used in the airborne tests and in a general comparison between the systems. In addition to these transfer functions, it is necessary to determine from carefully controlled closed system measurements levels of interference that correspond to specific degrees of degradation. In particular, Channels 1, 2, 3 and 5 were tested for a minimum interference threshold (MINIT) and a maximum interference threshold (MAXIT). Channel 3 carries narrow band radar data on three of the voice/data channels between 312 and 552 kHz.

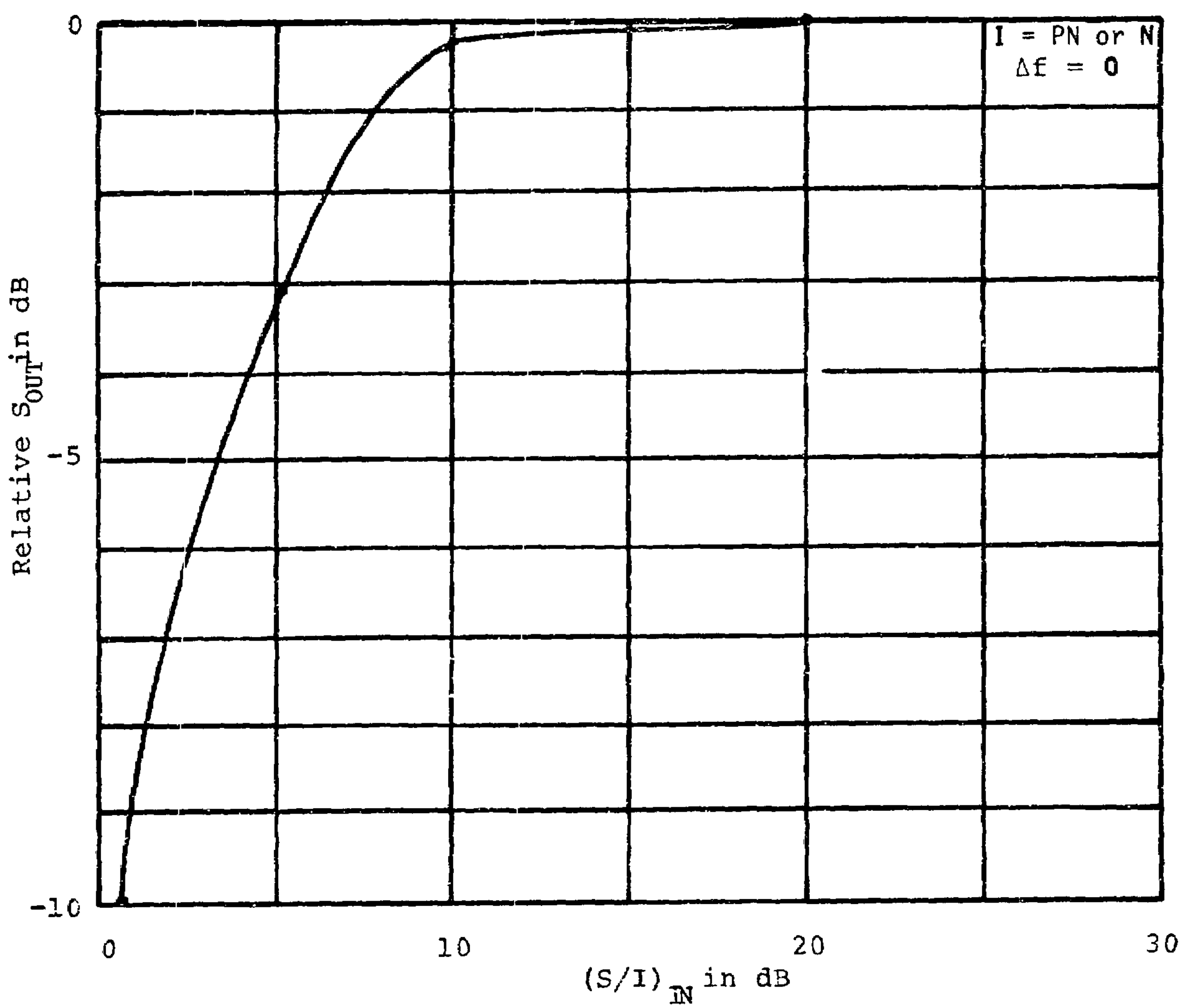


Figure 65 Channel 5 Pilot Desensitization Versus PN Interference

The performance of the digital channels was measured for the various channels and is shown in Table 18. All the data except Channel 3 digital was obtained by noting the level at which the threshold occurred on the PPI. The digital thresholds were obtained from a FAA computer program which calculated lost messages. The values given are at the point at which messages are first being lost.

FLIGHT TESTS

Introduction - The object of the flight tests was to measure in an operational or open system configuration actual FAA system degradation caused by the SHF SATCOM transmission. These measured interference levels were, however, only sample indications of overall link degradation. In order to determine how much degradation the overall FAA link experienced, it is necessary to use the results of the open system and closed system measurements along with a computer program that can generalize these results to the multihop multilink situation found in the total real environment. The following is, therefore, divided into:

(1) A discussion of the flight test measurements and how they compare with the ground tests.

(2) Probability considerations of random flight paths.

(3) Protection Ratio Contours [generated with computer simulation program (ATTIC).]

The flight tests were accomplished with the aircraft transmitting either a continuous wave (CW) or a Pseudo Noise (PN) signal of various power levels. In the CW mode, the major objective was to investigate antenna coupling between the aircraft and the microwave receiver; consequently, overhead passes, inbound and outbound radial runs and orbits at approximately 180

TABLE 18

FAA S/I THRESHOLDS*

Interference Type / Channel	PN		N		CW
	MINIT	MAXIT	MINIT	MAXIT	MINIT
RML-4, CH 1 Beacon	12	7	12	6	2
RML-4, CH 2 MTI/ Normal	15	10	15	10	2
RML-4, CH 2 (AM Subcarrier)	11		12		
RML-4, CH 3 Digital	10	9	9	8	
RML-4, CH 3 Synchro	7		6		
RML-6, MTI/Normal	29	25	29	25	16
RML-6, Decoded Beacon	13	10	9	8	6
RML-6, Uncoded Beacon	13	10	11	9	14
RML-4, CH 5 (Voice CH Comm & Cont)	10	0	10	0	
RML-4, CH 5 Pilot	10	5	10	5	

*At the Receiver Input and does not include a bandwidth correction factor. For PN and N interference, the inband (S/I) ratio would be increased 5 dB for the RML-4 and 0 dB for the RML-6.

nautical miles were performed. In the PN mode, degradation experienced by the FAA system from signals coupled through the main beam window was of primary concern; consequently, only main beam coupling orbits at approximately 180 nautical miles were tested. Both the RML-4 sites at Seales, Newport and Hardeeville, and the RML-6 site at Jacksonville airport were investigated for interference effects.

RML-4 CW Antenna Tests - To determine the amount of energy coupled into the FAA's RML-4 Microwave System at Seales, Georgia, the test aircraft flew the patterns shown in Figures 66 and 67. The flight patterns consisted of:

1. Radial runs to determine the coupling between the microwave main beam and the aircraft sidelobes.
2. Cloverleaf and offset patterns to determine the coupling between high overhead elevation angles of the periscope antenna and the backlobes of the aircraft antenna.
3. Orbit flights to determine coupling between the microwave main beam and the aircraft sidelobes.

The aircraft transmitted 10 kW CW power on a frequency of 8045 MHz. This is the frequency of Channel 4, the spare channel, of the RML-4.

After calibration of the Seales AGC, a direct measure of the energy coupled into the Seales antenna was obtained. For one test, the aircraft flew outbound from the Seales terminal along the boresight of the antenna at an altitude of 2[illegible] feet. During this test, the aircraft antenna was positioned at a +10° elevation angle pointed towards the Seales terminal. The actual flight path of the aircraft is recorded by FAA radars as shown in Figure 68 and indicate[illegible]ose agreement with the flight plan. The CW signal coupled into th[illegible]les antenna is shown in Figure 69. A limited amount of coupling [illegible]cted over the first 50 miles from Seales.

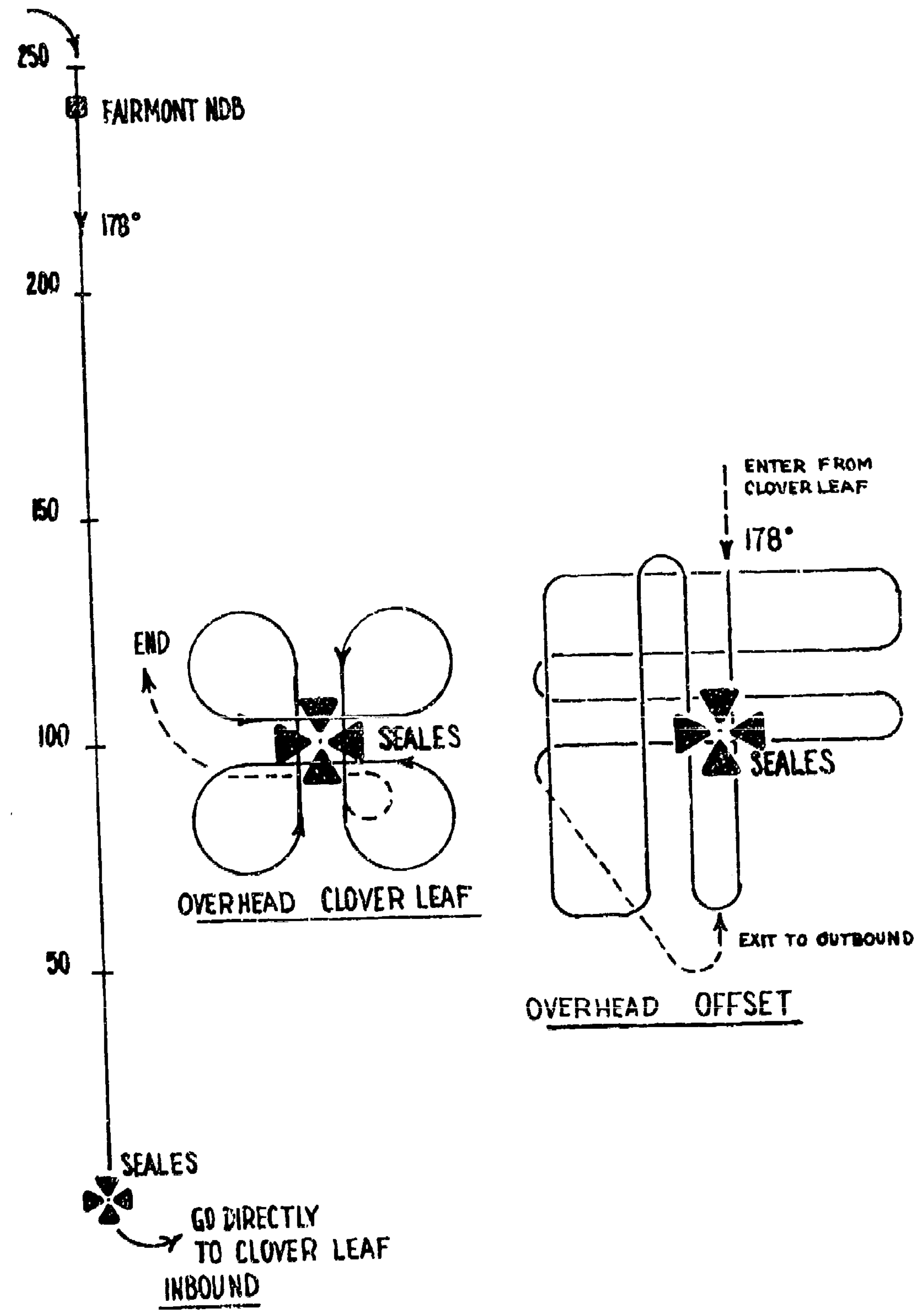


FIGURE 66. IDEAL FLIGHT PATTERNS FOR CW TEST

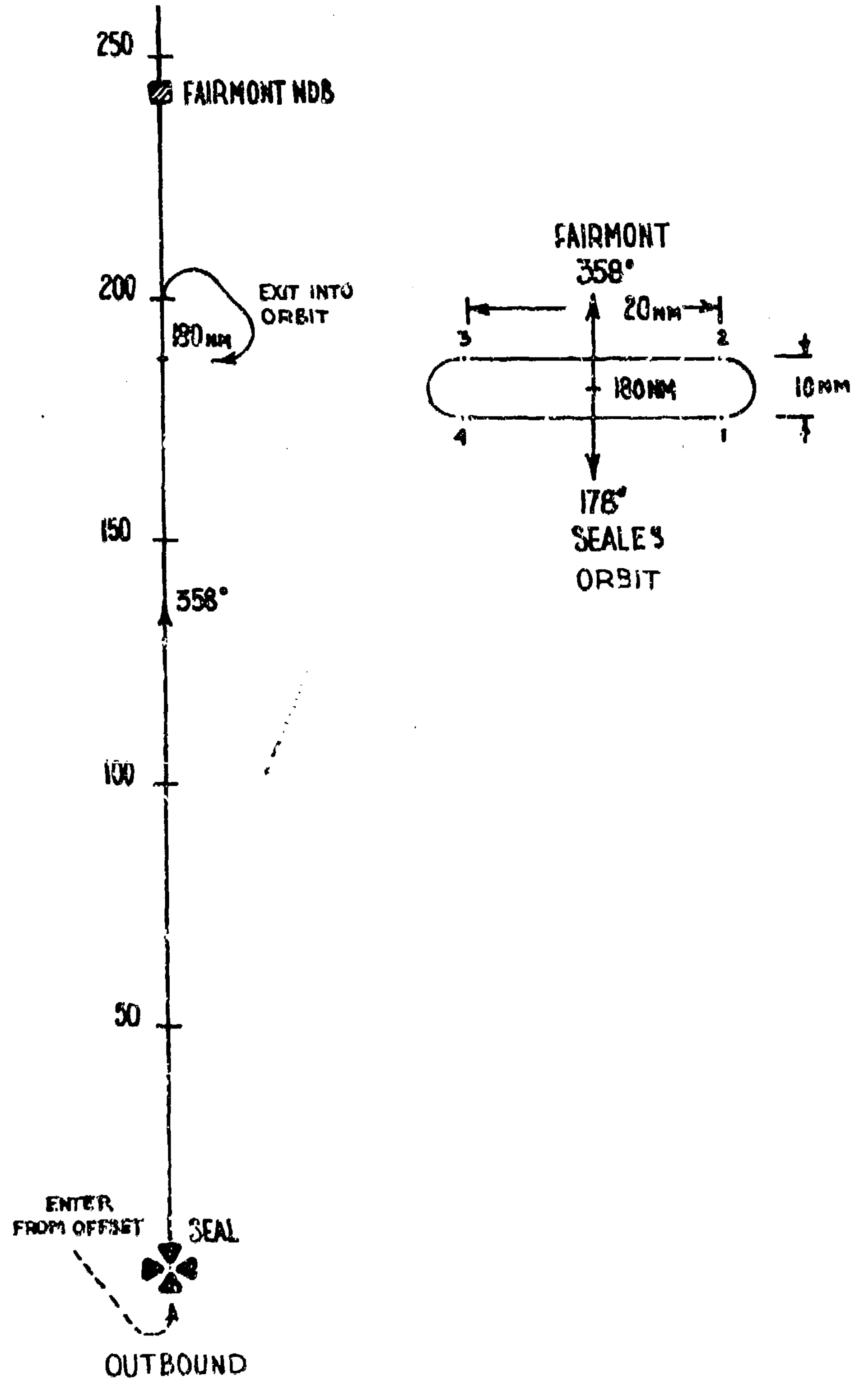


FIGURE 67. IDEAL RADIAL AND ORBIT FLIGHT PATTERNS

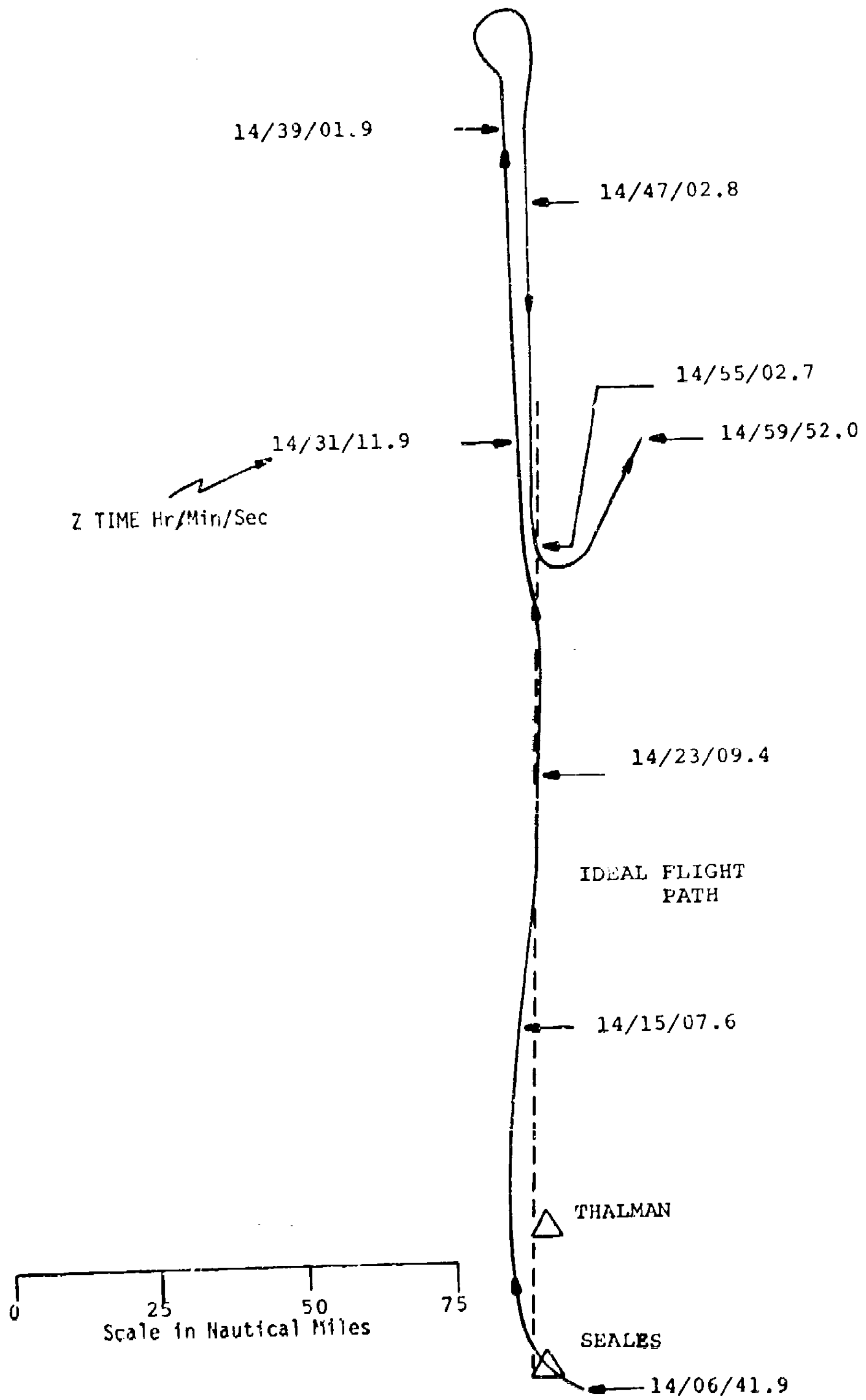


FIGURE 68 FAA RADAR MEASURED RADIAL FLIGHT PATH

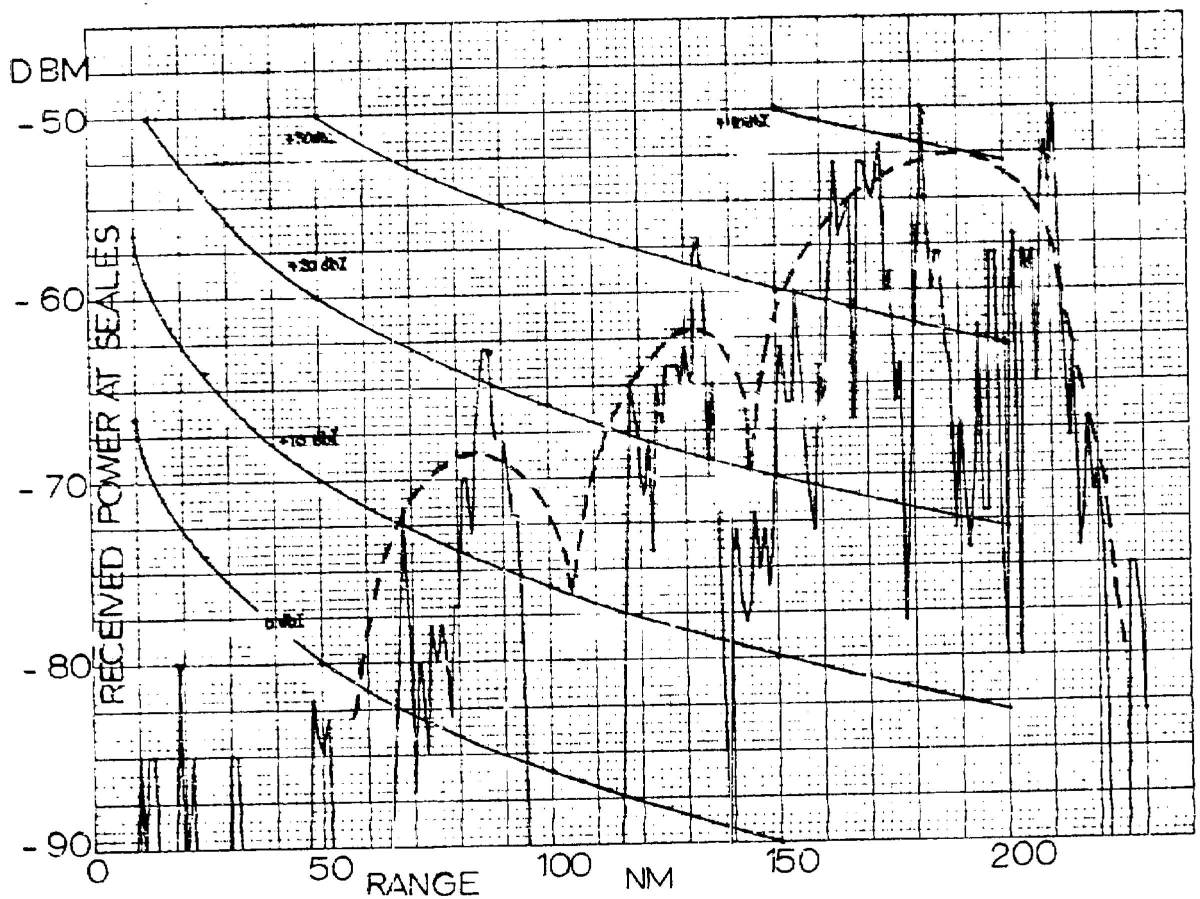


FIGURE 69 RML-4 RECEIVED POWER AT SEALES FOR RADIAL RUN

At approximately 80 miles, the coupling increased as the aircraft encountered the second sidelobe of the Seales antenna. Around 125 miles, the aircraft encountered the first sidelobe of the Seales antenna and greater coupling resulted. At 160 to 190 miles from Seales, the aircraft encountered the main beam of the Seales antenna. The signal strength actually encountered, varied from the calculated received signal strength due to multipath enhancements and cancellations. In the region of 160 miles from Seales, a multipath fade would be expected for every 10 miles traveled. Deep multipath nulls are obvious in the recorded data.

In order to calculate the expected received signal strength at Seales, an aircraft antenna gain was assumed. With the aircraft antenna positioned at 10° elevation angle pointed towards Seales, the gain is approximately -1 dBi (see Figure 3) with a variation of +3 to -13 dB. With the -1 dBi antenna gain and a 10 kW CW transmitting power, the curves were plotted indicating various amounts of antenna gain for the Seales antenna.

In Figure 69, contours are shown for 0, +10, +20, +30 and +40 dB gain of the Seales antenna. The +40 dB of gain intercepts the measured beam pattern in the area of 160 miles where the main beam reaches the aircraft altitude.

A commonly used antenna in the FAA system is a periscope or fly swatter type. This antenna has a dish on the ground pointed up to a passive reflector mounted on a tower. The passive reflector redirects the energy horizontally to the next station. Since the parabolic antenna is looking straight up, there is a question as to how much energy will be coupled into that antenna as the aircraft flies directly over the terminal. To measure

this coupling, the test aircraft flew both directly overhead and slightly offset from terminal. The actual overhead flight patterns are shown in Figure 70. The results of a typical overhead pass are shown in Figure 71. Figure 71A shows the actual energy coupled into the FAA antenna system. Figure 71B shows the energy density taken on a separate broad-beam antenna pointed toward the aircraft. Note in Figure 71B the gradual rise in the recorded energy. This energy peaks over a broad angle at the same time the FAA antenna system has only a few narrow spikes of response. This indicates that the beam pattern overhead for the periscope type antenna is very narrow. These results also show that even when these peaks are encountered, the actual received energy is very low due to shielding of the aircraft antenna by the aircraft structure.

The aircraft also flew offset from directly overhead as indicated in the actual flight paths shown in Figure 72. These patterns were flown alongside the Seales terminal parallel to the direction in which the ground antenna points at an offset distance of 2, 5, 10 and 20 miles. They were also flown in front and behind the terminal, perpendicular to the direction the ground antenna points, at the same set of distances. The results of these coupling tests are shown in Figure 73. The data runs, two miles behind the antenna and 20 miles alongside the antenna, produced no measurable signal coupling. The coupling data is similar to the overhead flights in that the coupling occurs only in narrow areas and is of relatively low intensity.

The other type of CW data which was taken was a racetrack orbit flown in the main beam of the antenna at approximately 170 to 180 nautical miles from the ground terminal. This orbit was positioned such that during the

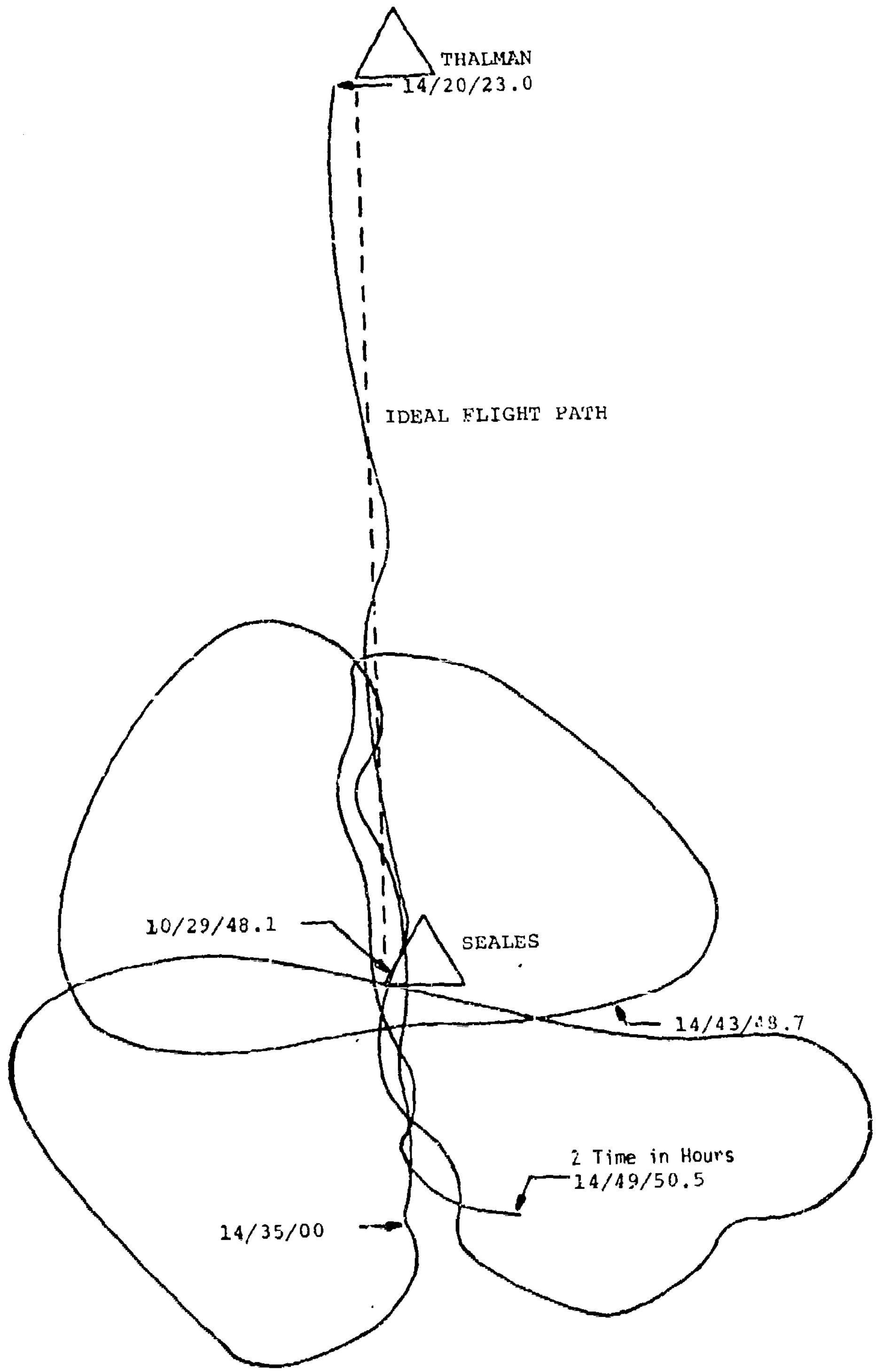
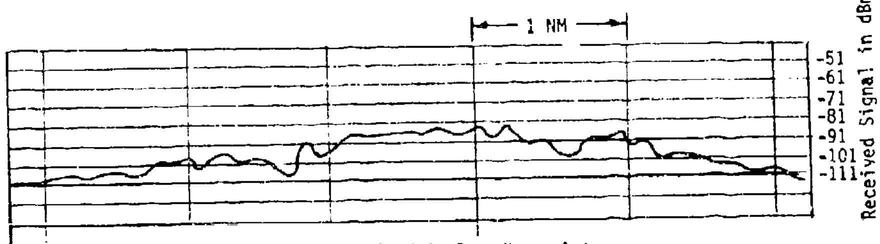
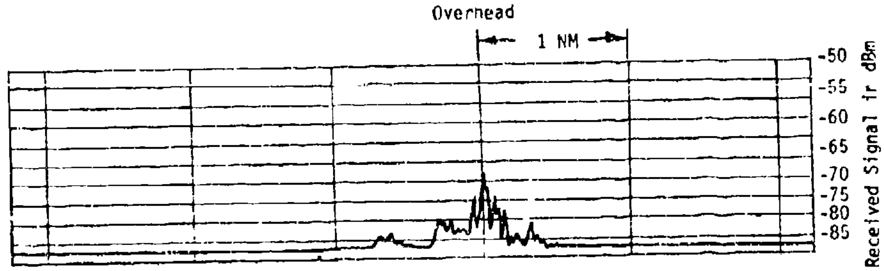


FIGURE 70 FAA RADAR MEASURED OVERHEAD FLIGHT PATH



B. Energy Density Received On Broadbeam Antenna



A. Energy Coupled Into RML-4 Antenna System

FIGURE 71 RECEIVED INTERFERENCE FOR OVERHEAD FLIGHT PATH

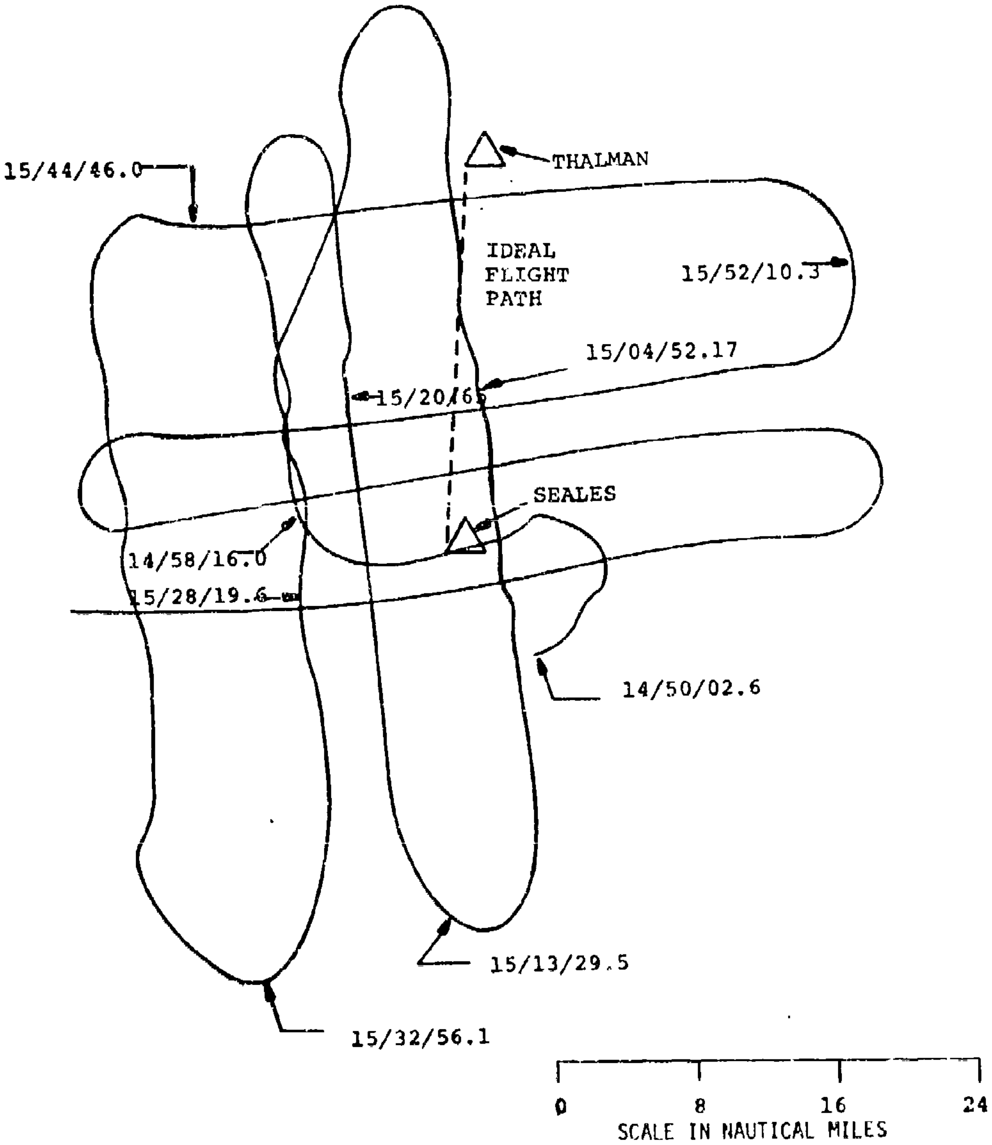


FIGURE 72 FAA RADAR MEASURED OFFSET FLIGHT PATH

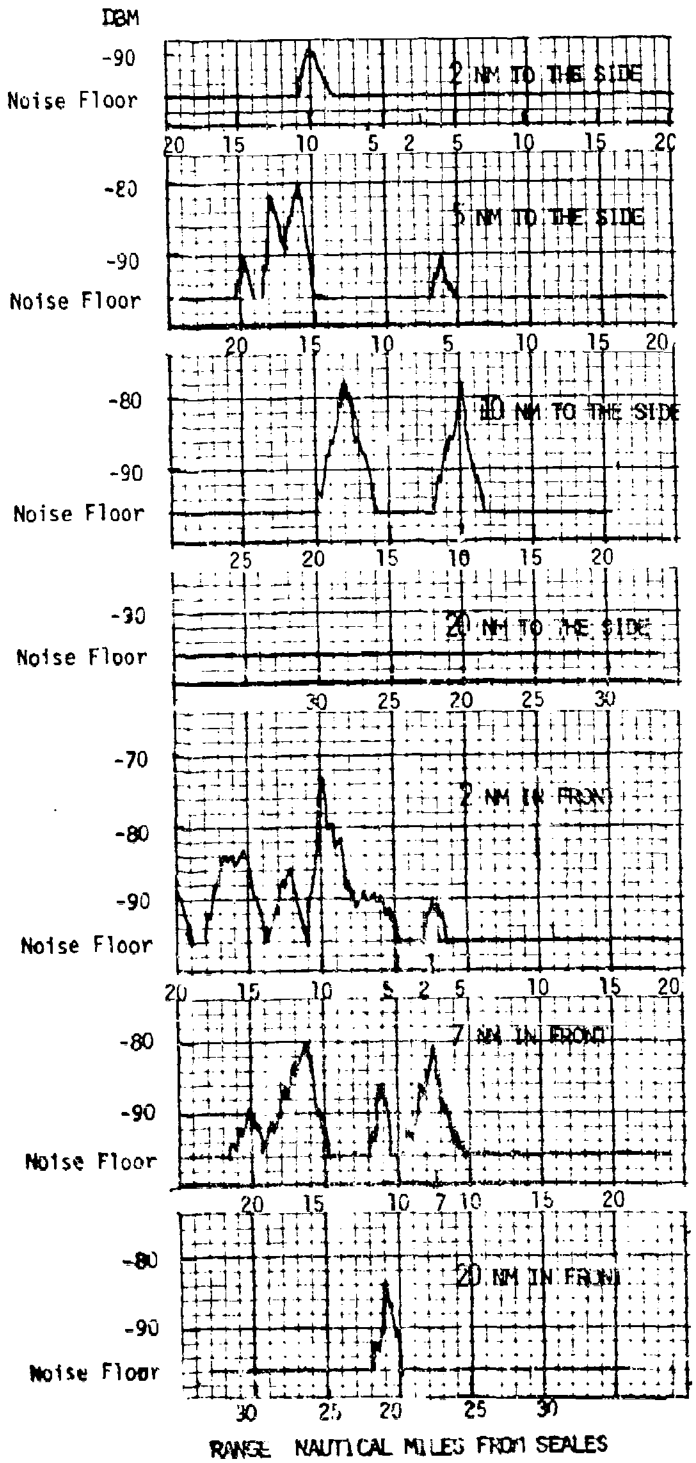


FIGURE 73 SIGNALS RECEIVED BY RML-4 ANTENNA SYSTEM FOR OFFSET FLIGHT PATH

long straight portions, the aircraft would pass through the main antenna beam. Typical CW and PN orbits (the PN orbit will be discussed in the next section) as measured by FAA radars are shown in Figure 74, and indicate that the aircraft passed through the main beam. Results of one of these orbits can be seen in Figure 75 where the energy coupled into the ground system was recorded. The width of the antenna beam and the measured amplitude agree well with the system calculations as discussed in the PN section.

Conclusions -

1. Signal levels indicated that the aircraft flew through the main beam window from 160 nautical miles to 210 nautical miles at an average peak CW interference of -50 dBm to -53 dBm. This agrees with theoretical calculations and is further discussed in the PN section.
2. Received signal levels indicated that at distances less than 80 nautical miles, no potential interference problem would have been created to the FAA system from the periscope antenna. At this distance, the total antenna coupling from the microwave receiver and the aircraft was approximately +10 dBi.
3. The peak overhead received signal level from the periscope antenna was approximately -72 dBm. This peak signal strength occurred for only a period of approximately 2 seconds which indicates a very narrow vertical periscope antenna pattern. These results also indicate heavy shielding of the aircraft antenna by the aircraft structure.

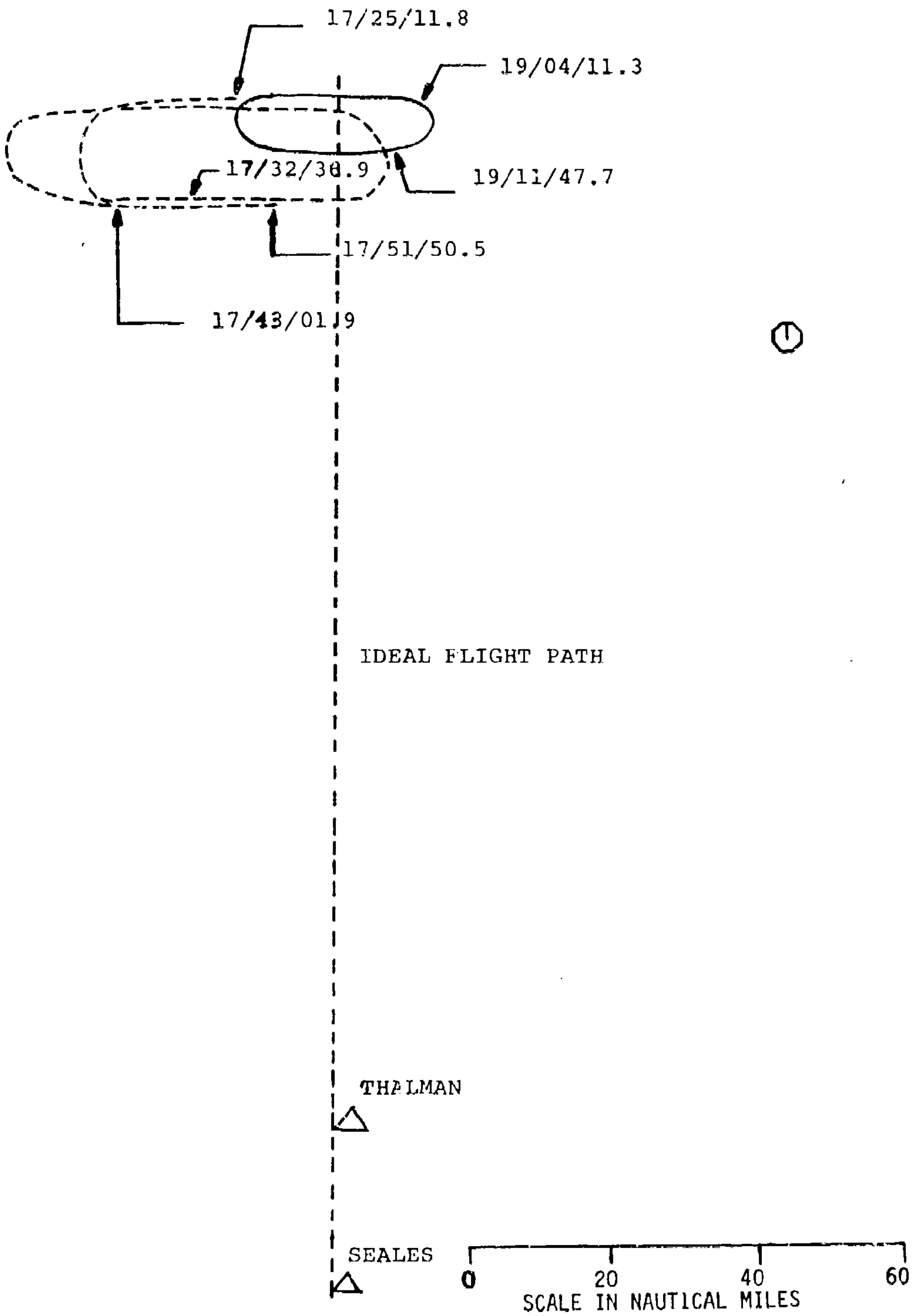


FIGURE 74 FAA RADAR MEASURED ORBIT FLIGHT PATH

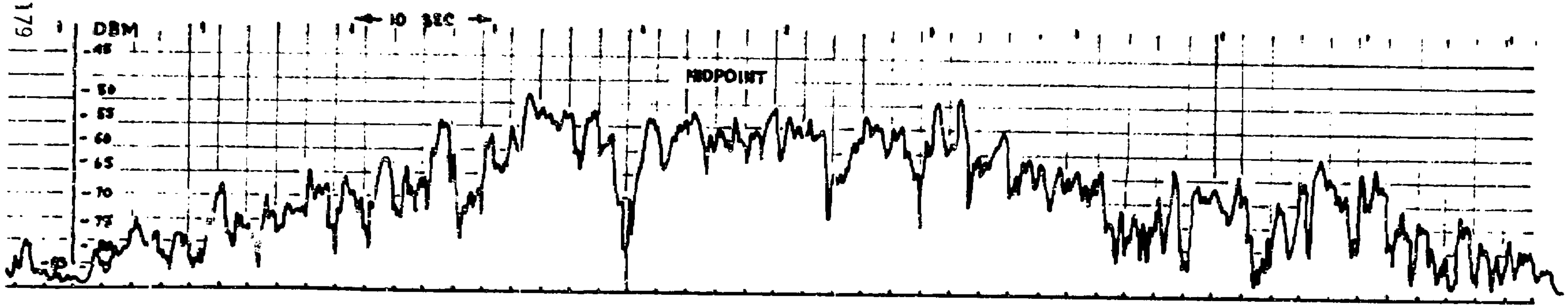


FIGURE 75 CW ORBIT ACROSS SEALES WINDOW AT 160 NM

RML-4 PN DEGRADATION TESTS

The PN flight tests were divided into tests of the degradation experienced by Channels 1, 2 and 3. The flight tests were flown with the same orbits described in the CW tests. Received interference from a typical PN orbit is shown in Figure 76. All tests were performed with a 1° antenna elevation (the minimum or worst case elevation angle). Interference effects were recorded on video tape for Channel 1 (Beacon) and Channel 2 (MTI/Normal). The interference power at the RML-4 receiver input at Seales was also recorded in terms of the slot noise in the 2.438 MHz channel. For Channel 3, errors recorded and the messages lost, as indicated by an FAA error check program, were recorded along with the 2.438 MHz slot noise. The subjective effect of the interference on the PPI synchronization was also noted for Channel 3 at the ARTCC center. The received slot noise and the AGC voltage were recorded on an HP 7414 oscillographic strip chart recorder. The following are brief discussions and analysis of selected strip chart recordings which show the peak coupling of interference power as the aircraft passed through the main beam of the RML-4 antenna.

Channel 1 - 10 kW - The interference effect to the Channel 1 beacon signal for the case of a 10 kW PN signal from the SHF SATCOM antenna looking at the site at Seales is indicated in Figure 76. This figure shows the PN slot noise and the desired signal level as recorded on an oscillograph strip chart. A summary of the results of a comparison between the flight test measurements and the closed system ground tests are shown in Table 19 The first row shows the average input desired signal level S_{IN} which was estimated directly from Figure 76. The next row shows the minimum interference threshold (MINIT) in terms of the signal-to-interference ratio

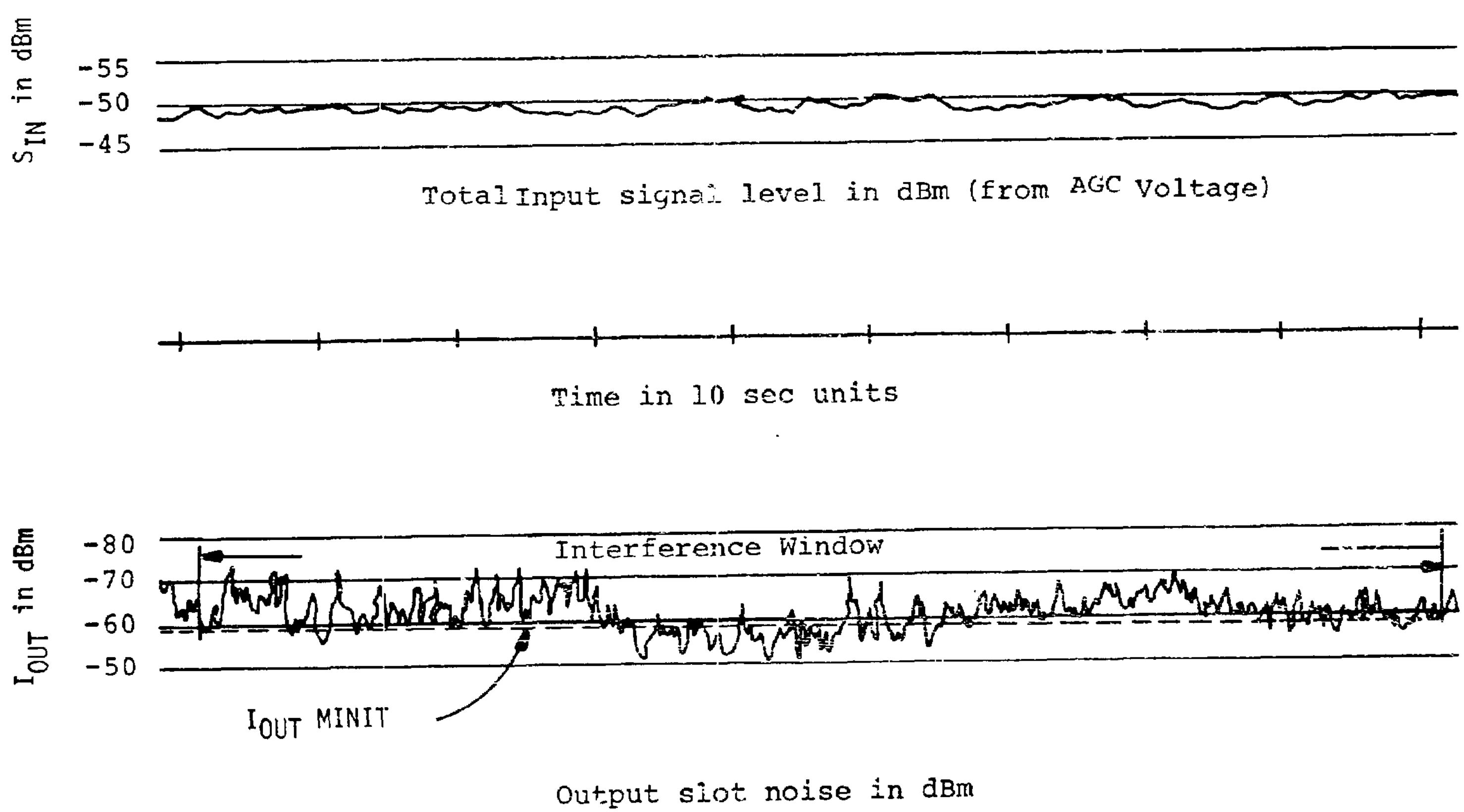


FIGURE 76 CHANNEL 1 SLOT NOISE WITH 10 kW PN INTERFERENCE

TABLE 19

COMPARISON BETWEEN FLIGHT TEST AND CALCULATED INTERFERENCE LEVELS

TYPE OF TEST / PARAMETER	RML-4									RML-6
	Channel 1 10 kW Towards	Channel 1 1 kW Towards	Channel 2 10 kW Towards	Channel 3 10 kW Towards	Channel 3 10 kW Away	Channel 3 100 W Towards	Channel 3 5 kW Towards	Channel 3 1 kW Towards	Multiple Window (Channel 2) Towards	MTI/Normal 10 kW Towards Reflector
$\bar{S}_{IN}$ in dBm	-49	-48	-49	-48	-48	-49	-48	-49	-49 (assumed)	-36
$(S/I)_{MINIT}$ in dB	12	12	15	10	10	10	10	10	15	29
$\bar{I}_{IN,\ MINIT}$ in dBm	-61	-60	-64	-58	-58	-59	-58	-59	-64	-65
$I_{OUT,\ MINIT}$ in dBm	-59	-59	-62	-57	-57	-57	-57	-57	-62	-63
$T > MINIT$ in sec	~90	0	~85	85	0	0	7	0	75	~20
$\hat{I}_{OUT,\ MEAS}$ in dBm	-51	-63	-50	-50	-59	-70	-55	-60	-52	-55
$\hat{I}_{IN,\ MEAS}$ in dBm	-53	-65	-52	-51	-60	-72	-56	-62	-54	-57
$\hat{I}_{IN,\ CALC}$ in dBm	-54	-64	-54	-54	-66	-74	-57	-64	~-54	-54
$\Delta\hat{I}_{IN}$ in dB	1	-1	2	3	6	2	1	2	0	-3
$T_{VIDEO\ TAPE}$ in sec	~90	0	60 Heavy 60 Light	~85	0	0	0	0	~90	short burst
Comments	Heavy Inter-ence	No Inter-ference	Heavy Inter-ence	98% Lost Messages	0% Lost Messages	0% Lost Messages	1.3% Lost Messages	0% Lost Messages		PPI Display

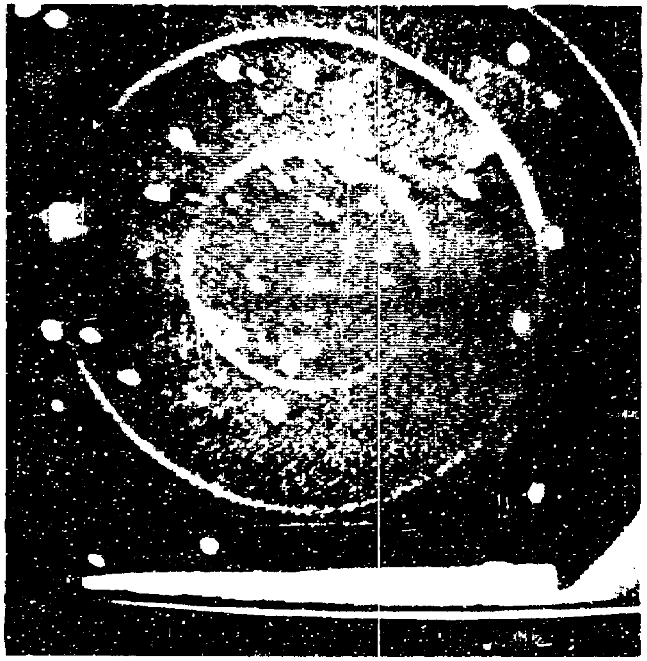
as previously measured in the closed system tests and summarized in Table 18. The average input MINIT value is shown in the next row which was obtained from Equation 3-8:

$$I_{IN,\ MINIT}\ (dBm) = \bar{S}_{IN} - (S/I)_{MINIT} \qquad (7\text{-}3)$$

where

$\bar{S}_{IN}$ = average input signal level

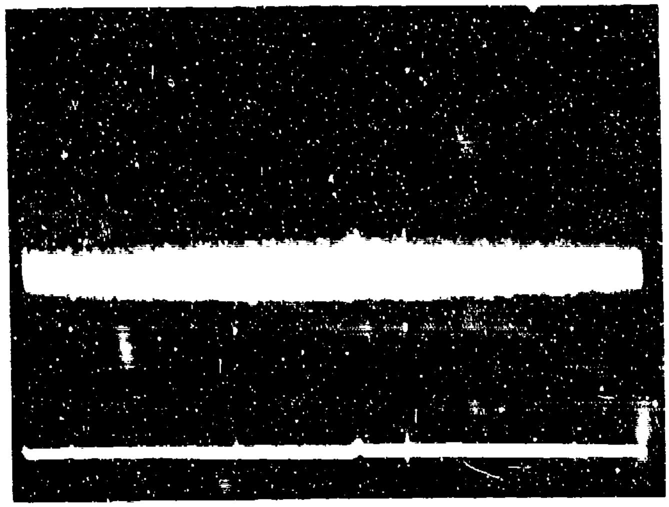
The strip chart was recorded in terms of the output slot noise interference level. Figure 57 shows the results of the ground test calibration of the output slot noise level as a function of the input (S/I) ratio. The MINIT S/I of 12 dB corresponds to an interference output level of -59 dBm. Figure 76 shows that the interference exceeded the -59 dBm threshold level for approximately 90 seconds. This interference should, therefore, be seen on the video recording of Channel 1 for the same length of time. Interference was recorded on the beacon video tape for approximately 90 seconds which agrees closely with the strip chart records. Severe interference was also noted on the beacon video. Severe interference is also evident in the slot noise recording of the main portion of the strip chart where the interference level equals -53 dBm and therefore exceeds the MINIT threshold by approximately 9 dB. According to Table 18 this exceeded the maximum interference threshold of -57 dBm [$(S/I)_{IN}$ = 4 dB] by 4 dB and, therefore, would indicate severe interference for the 20-second period that the signal was at this level. Typical pictures of what Channel 1 video looked like with no interference and during the peak interference window, is shown in Figure 77. This figure shows a severe level of degradation for the peak portion of the interference which agreed with the closed system measurements. Figure 78 shows A-scope



Channel 1 PPI Display With No Interference

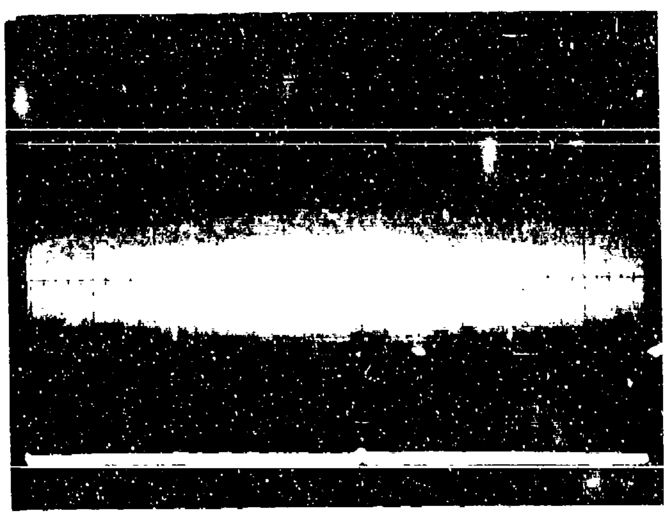
Channel 1 PPI Display With 10 kW PN Interference

FIGURE 77 CHANNEL 1 PPI DISPLAY WITH AND WITHOUT INTERFERENCE



4:1 Signal/Interference

No Interference



1:1 Signal/Interference

No Interference

FIGURE 78 CHANNEL 1 A SCOPE DISPLAY WITH AND WITHOUT INTERFERENCE

pictures with no interference and during a portion of the interference. This figure shows severe interference since the interference in the worse case exceeds the standard FAA 4:1 signal-to-noise criteria.

The next area examined was a comparison of the received interference level and the calculated interference level using typical antenna gain and propagation loss values. The average peak slot noise level in Figure 76 was approximately -51 dBm which corresponds to an input (S/I) ratio of 4 dB (see Figure 57). This, therefore, translates to an input interference level of -53 dBm. The average peak values were used because the antenna gain values are also based on average peak (worst case) specifications. The expected interference level at the receiver input for the case considered was

$$I_{IN}\ (\text{dBm}) = I_T + G_R + G_T - L_A - L_{WG} \qquad (7\text{-}7)$$

The RML-4 antenna gain at Seales was listed as 39 dB in the Government Master File (GMF). The aircraft antenna gain was previously discussed and showed a major sidelobe gain of approximately -1 dBi. The orbits were performed at a distance of approximately 170 nautical miles. The atmospheric absorption at 8 GHz is shown to be 2 dB in Figure 5. Substituting these values, the peak received power was calculated as:

$$I_{IN} = 70\ \text{dBm} + 30\ \text{dB} - 1\ \text{dB} - 160\ \text{dB} - 2 = -54\ \text{dBm} \qquad (7\text{-}4)$$

This value does agree with the average peak measured value. The second level is caused by the aircraft motion relative to the microwave antenna patterns.

Channel 1 - 1 kW - The interference effect to the Channel 1 beacon signal for the case of a 1 kW PN signal from the SHF SATCOM antenna looking at the site at Seales is indicated in Figure 79.

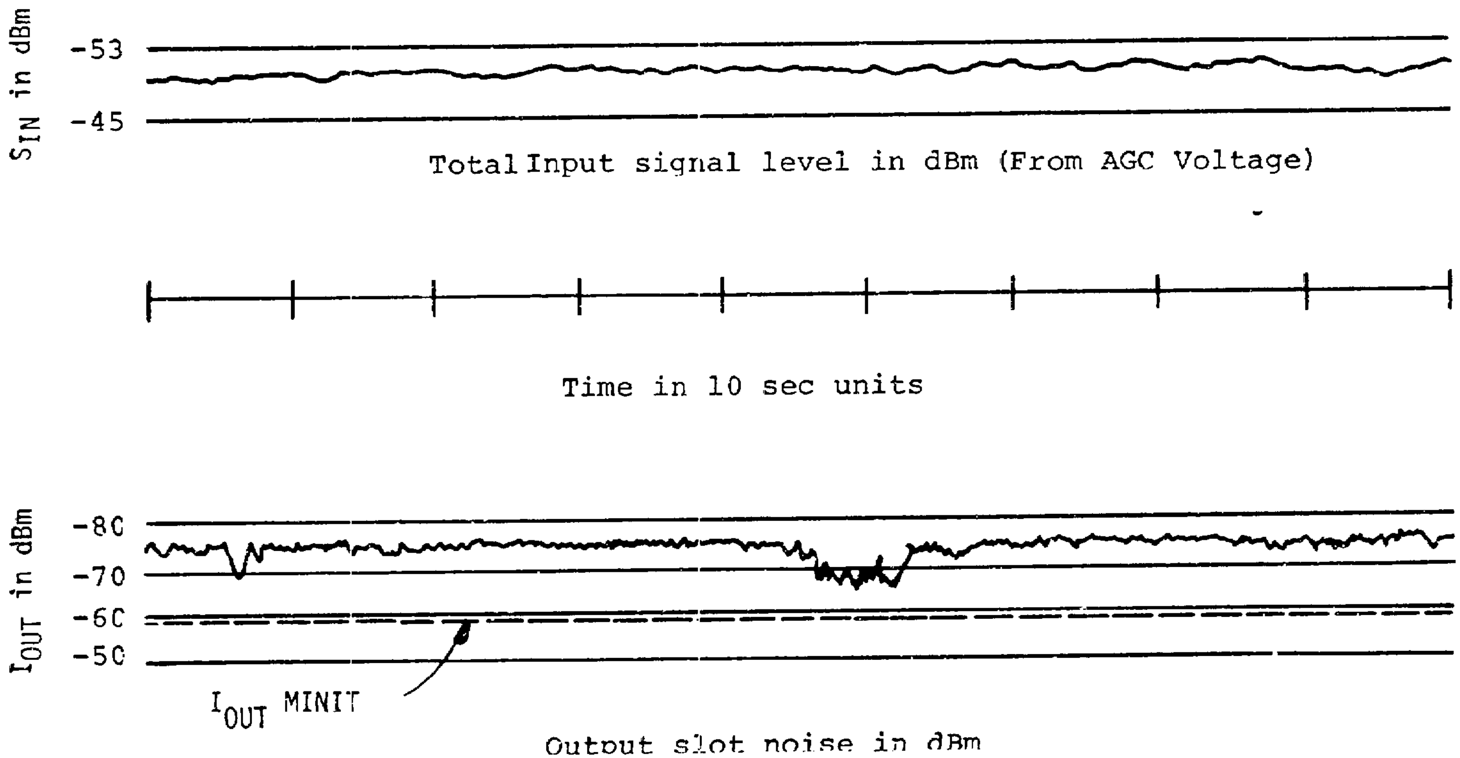


FIGURE 79 CHANNEL 1 SLOT NOISE WITH 1 kW PN INTERFERENCE

A summary of the results of a comparison between the flight test measurements and the closed system ground tests is shown in Table 19. The method used to obtain these values was previously discussed. For the 1 kW case, the peak interference measured was less than the MINIT level and, therefore, no interference was expected or noted on the beacon video display. The calculated interference level was 2 dB higher than the measured value.

Although no interference effects were expected or observed for this 1 kW case, it does not mean that this interference level could be continuously tolerated since fading statistics of the desired signal also need to be considered. This will be discussed further in the section on probability considerations.

Channel 2 - 10 kW - The interference effect to the Channel 2 MTI/Normal signal for the case of a 10 kW PN signal from the SHF SATCOM antenna looking at the site at Seales is indicated in Figure 80. A summary of the results of a comparison between the flight test measurements and the closed system ground tests are shown in Table 19. The MTI/Normal video display had heavy interference for approximately 60 seconds and light interference for approximately 60 seconds. This agrees closely with the oscillograph recordings illustrated in Figure 80 where 85 seconds of interference above the MINIT level is shown. Figure 81 shows typical pictures of the MTI/Normal display with and without interference. The peak interference level shown in Figure 81 constitutes unacceptable degradation.

The calculated peak interference level was 1 dB less than the measured value.

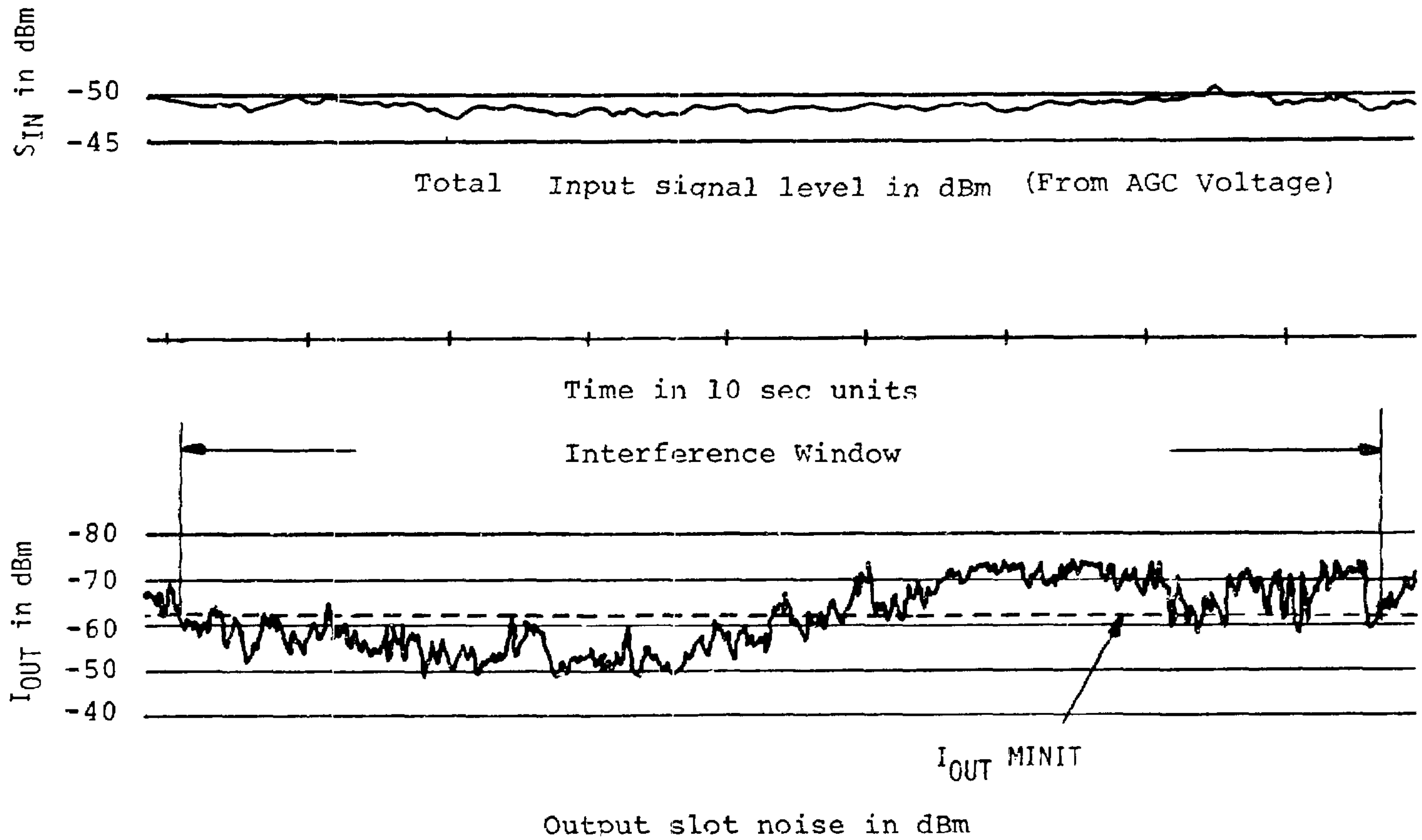
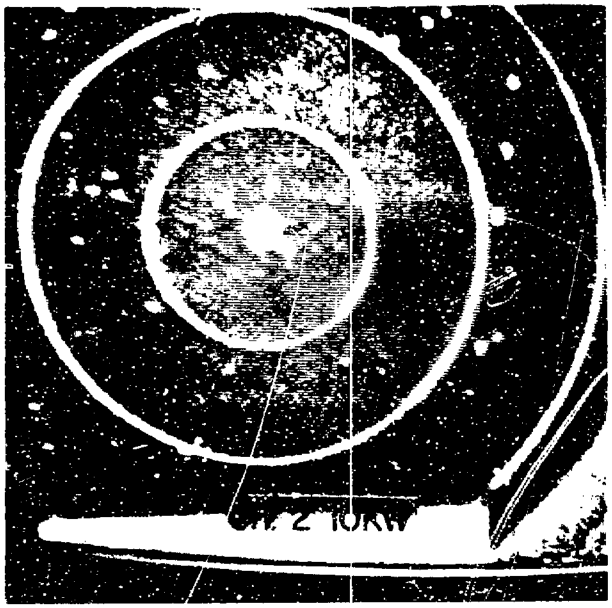
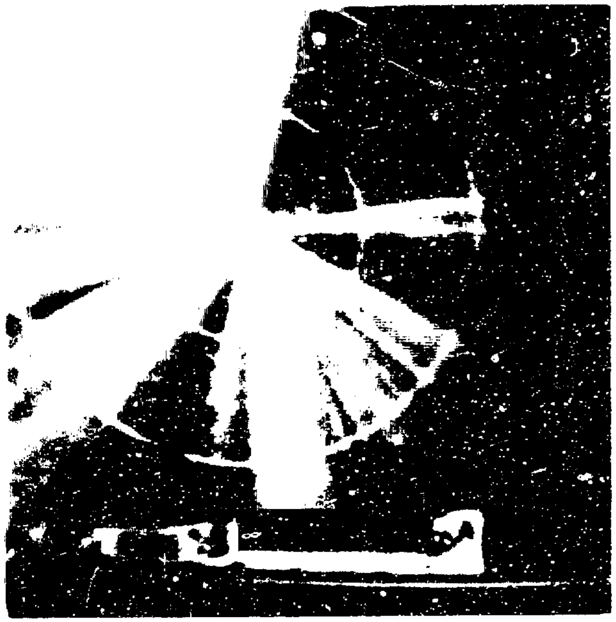


FIGURE 80 CHANNEL 2 SLOT NOISE WITH 10 kW PN INTERFERENCE



Channel 2 MTI/Beacon Display With No Interference



Channel 2 MTI/Beacon Display With 10 kW PN Interference

FIGURE 81 CHANNEL 2 MTI/BEACON DISPLAY WITH AND WITHOUT INTERFERENCE

Channel 3 - 10 kW - The interference effect to the Channel 3 narrow band digital signals for the case of a 10 kW PN signal from the airborne SHF SATCOM antenna, looking at the site at Seales, is illustrated in Figure 82.

A summary comparison of flight test measurements and closed system ground tests are shown in Table 19.

The interference exceeded the MINIT (or MAXIT) level for approximately 85 seconds and should have created a large number of errors in the digital messages. Message errors were recorded by the FAA CD Quality Precheck Program previously discussed. A summary of the CD Quality Precheck errors for all the Channel 3 interference tests "events" are shown in Table 20. During the main "window" portion of event 25 (the test being analyzed), 1315 messages were sent and only 29 were received. The interference signal levels were therefore clearly too high. This conclusion can also be reached by examining the data on Figure 82 and noting that the interference exceeded the MINIT threshold by 7 dB. Since the difference between the MINIT and MAXIT from the closed system measurements is only 1 dB, this clearly shows that unacceptable errors should be received. The time that the interference is above the slot noise threshold level was approximately 85 seconds. The average peak interference level was 2 dB higher than calculated for this event.

Channel 3 - 10 kW, Away - The interference effect to the Channel 3 narrow band digital signal for the case of a 10 kW PN signal from the airborne SHF SATCOM antenna looking away from the site at Seales, is indicated in Figure 83.

A summary of comparisons between the flight test measurements and the closed system ground tests are shown in Table 19. The peak interference

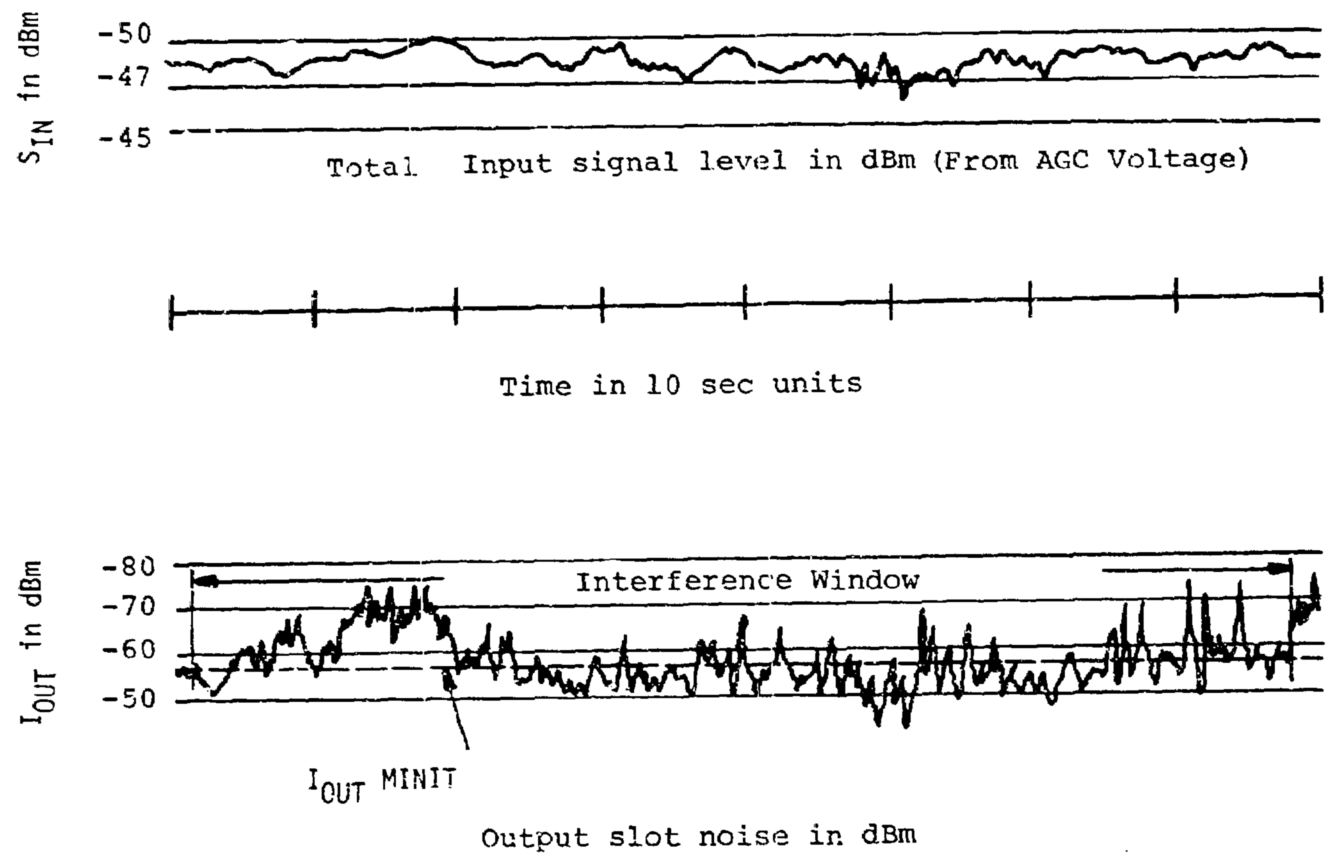


FIGURE 82 CHANNEL 3 SLOT NOISE WITH 10 kW PN INTERFERENCE

TABLE 20

CHANNEL 3 FLIGHT TEST DATA SUMMARY

DATE	EVENT	INTERFERED*	NON-INTERFERED**	MESSAGES LOST	ANTENNA POSITION	POWER
5/19/75	22	1402	1941	539	Towards	10 kW
"	23	1179	1648	469	"	"
"	25	29	1315	1286	"	"
"	26	400	1553	1153	"	"
"	27	292	1326	1034	"	"
"	28	2905	2905	0	Away	"
"	29	1509	1535	26	"	"
"	30	2023	2023	0	"	100 W
"	31	2218	2218	0	"	"
"	32	1084	1084	0	"	10 kW
"	33	1096	1096	0	"	100 W
"	34	1852	1852	0	Towards	"
"	35	1638	1638	0	Away	"
"	36	1574	1574	0	"	10 kW
5/20/75	9	1270	1790	530	Away	10 kW
"	10	2466	2499	33	Towards	5 kW
"	11	1913	1913	0	"	5 kW
"	12	1823	1823	0	"	1 kW
"	13	1308	1308	0	"	"
"	14	1470	1819	349	"	10 kW
"	15	1565	1575	10	"	"
"	16	2081	2081	0	Away	"
"	17	1621	1621	0	"	"

*RML-4 messages (interfered with messages from Jedburg)

**Transmitted via telephone lines (non-interfered with messages from Jedburg)

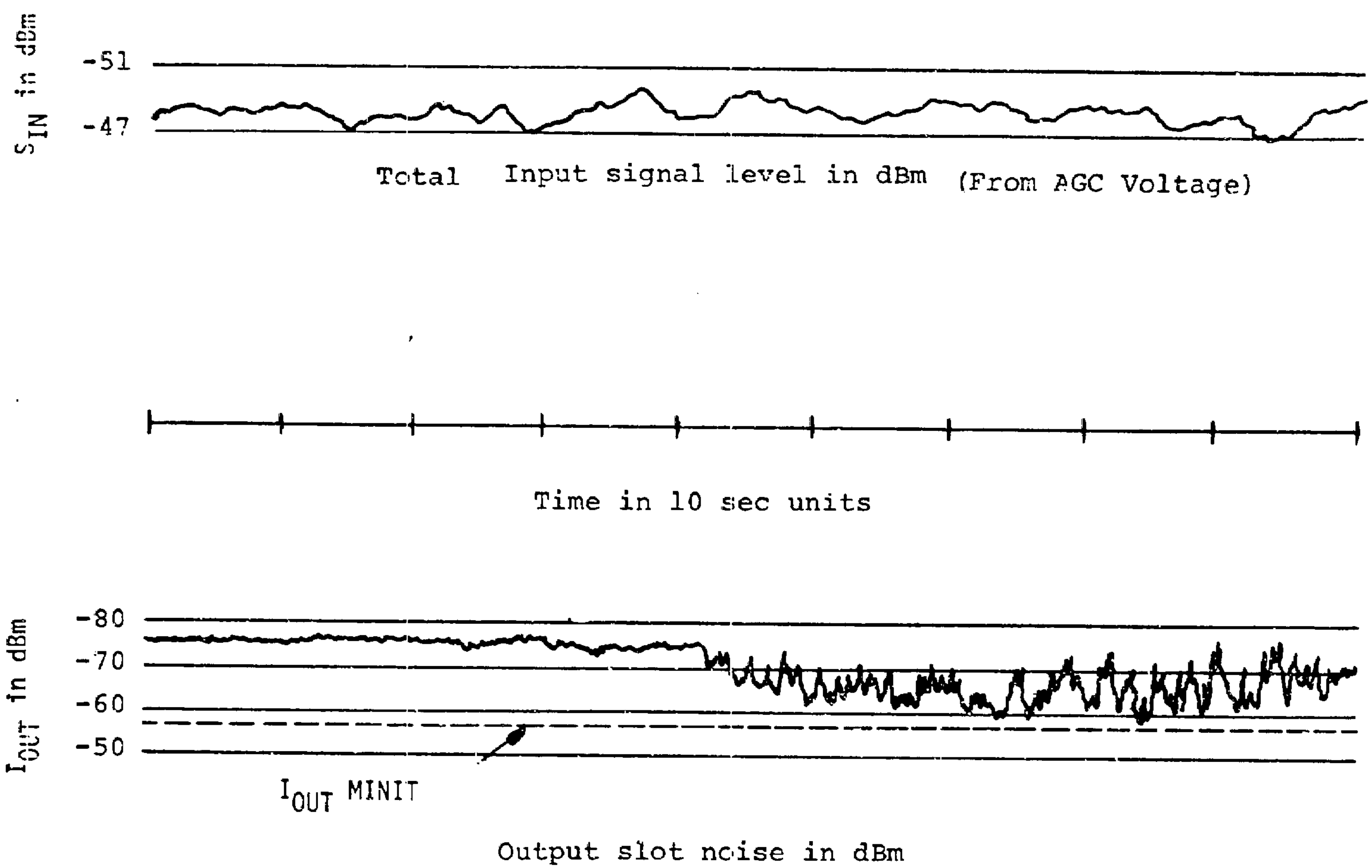


FIGURE 83 CHANNEL 3 SLOT NOISE WITH 10 kW PN INTERFERENCE, AWAY

was less than the closed system interference threshold level, therefore, no errors should be generated. This was confirmed by the CD Quality Precheck Program and is summarized in the results shown for event 28 in Table 20. The main difference between this test and the previous test was that the antenna was pointed 180° away from Seales with a 10° elevation angle rather than towards Seales. This reduced the received interference level by 9 dB. Examination of the airborne SHF SATCOM antenna pattern shown in Figure 3, indicates that the difference between the front porch and the back of the antenna is a difference of 12 dB [-1 dBi - (-13 dBi) = 12 dB]. The flight test measurements agreed with these antenna measurements within 3 dB.

Channel 3 - 100W - The interference effect to the Channel 3 narrow band digital signal for the case of a 100W PN signal from the airborne SHF SATCOM antenna looking at the site at Seales is indicated in Figure 84.

A summary of comparisons between the flight test measurements and the closed system ground tests are shown in Table 19. The peak interference was less than the closed system interference threshold level, therefore, no errors should be generated. This was confirmed by the CD Quality Precheck Program, the results of which are summarized for event 34 in Table 20. The main difference between this test and the previous full power test (10 kW towards) was that 100W was being transmitted. Although the overall peak interference level basically confirms a 20 dB reduction, the average peak level in the center of the window is down only about 11 dB. This probably indicates that major sidelobe antenna coupling occurred during this portion of the test.

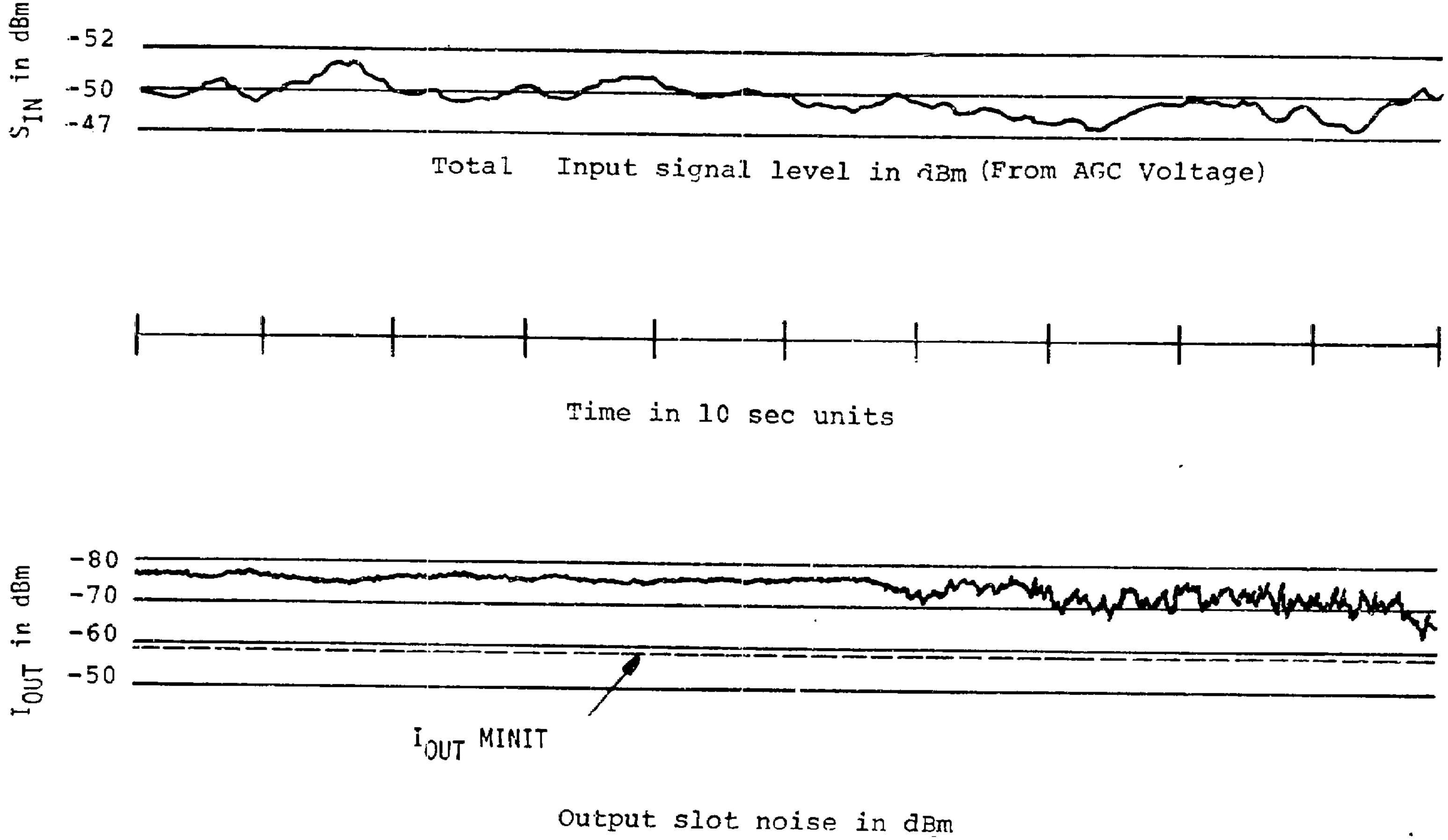


FIGURE 84 CHANNEL 3 SLOT NOISE WITH 100 W PN INTERFERENCE

Channel 3 - 5 kW - The interference effect to the Channel 3 narrow band digital signal for the case of a 5 kW PN signal from the airborne SHF SATCOM antenna looking at the site at Seales is indicated in Figure 85. Summary results of comparisons between the flight test measurements and the closed system ground tests are shown in Table 19. The peak interference was only a few dB greater than the closed system interference threshold level and occurs for only 7 seconds, therefore, few errors should be generated. This was confirmed by the CD Quality Precheck Program which showed 1.3% lost messages for the entire window time. This is shown in event 10 of Table 20. The main difference between this test and the full power test was that 5 kW is being transmitted instead of 10 kW. Although the peak interference level confirms a 3 dB reduction, the average peak level in the center of the window was narrower than the 10 kW case.

Channel 3 - 1 kW - The interference effect to the Channel 3 narrow band digital signal for the case of a 1 kW PN signal from the airborne SHF SATCOM antenna looking at the site at Seales is indicated in Figure 86. A summary of the results of a comparison between the flight test measurements and the closed system ground tests are shown in Table 19. The peak interference is less than the closed system interference threshold level and therefore indicates that no errors should be generated. This was confirmed by the CD Quality Precheck Program as shown in event 12 of Table 20. The main difference between this test and the previous full power test is that 1 kW was being transmitted instead of 10 kW. Although the peak interference level confirms a 10 dB reduction, the average peak level in the center of the window was down an additional 5 dB.

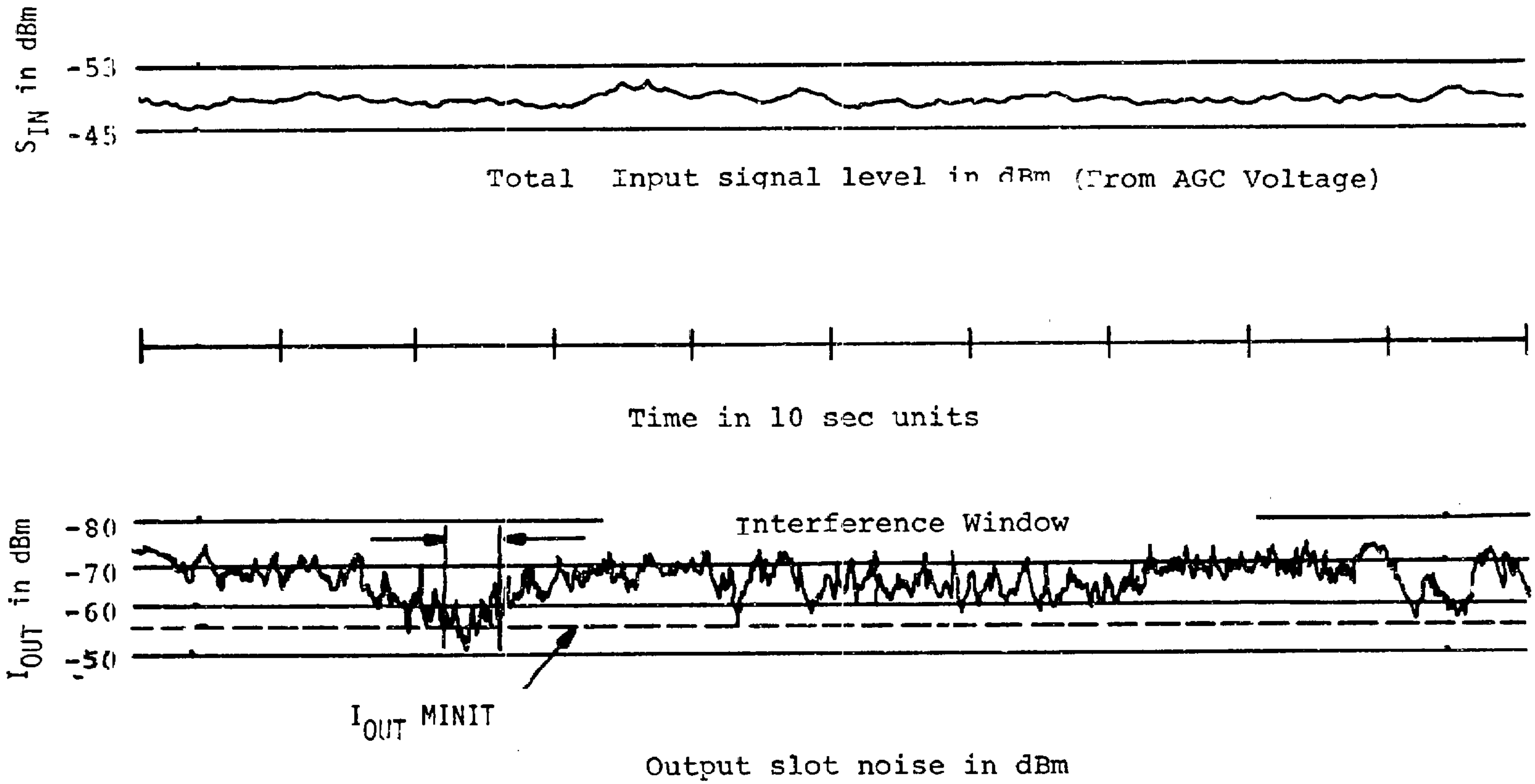


FIGURE 85 CHANNEL 3 SLOT NOISE WITH 5 kW PN INTERFERENCE

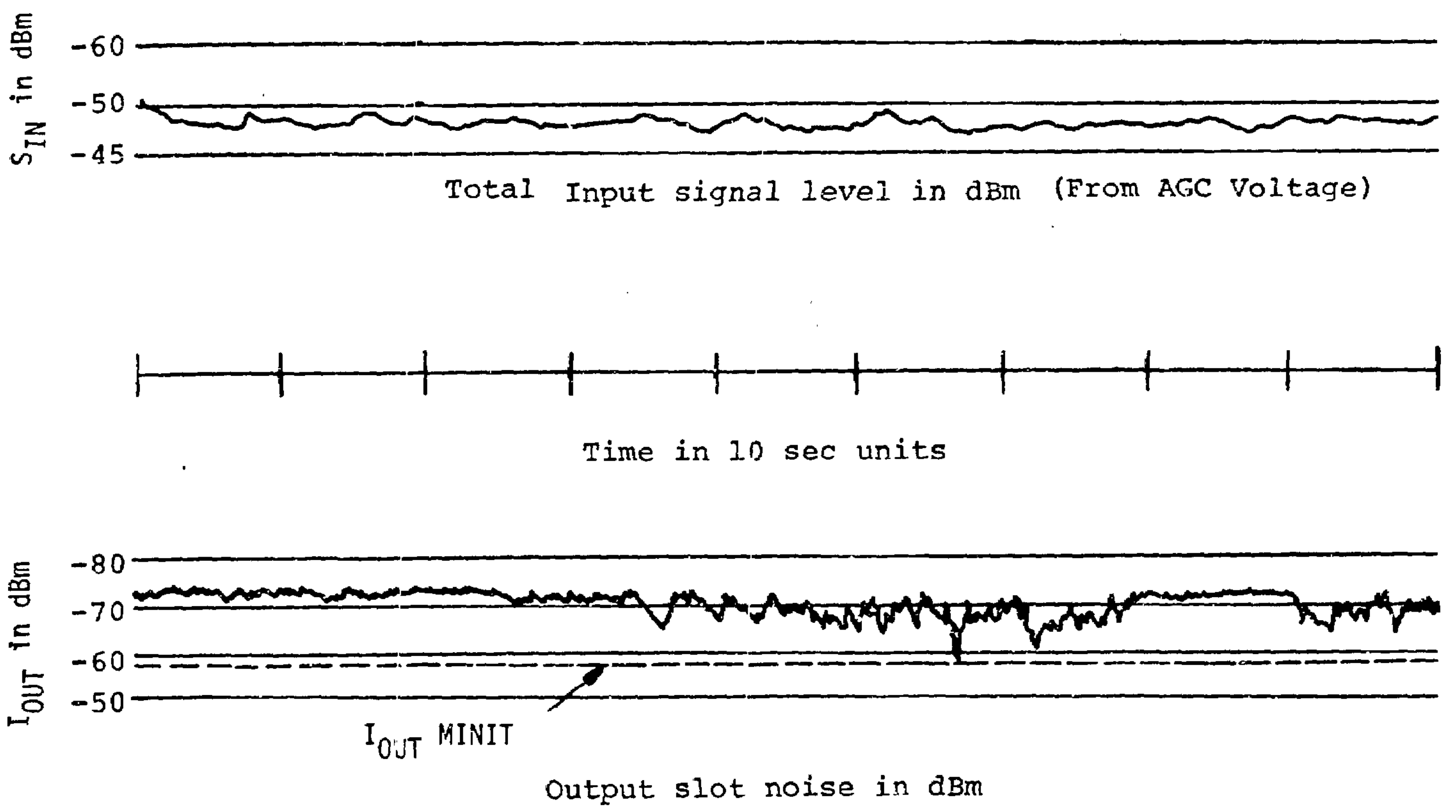


FIGURE 86 CHANNEL 3 SLOT NOISE WITH 1 kW PN INTERFERENCE

Channel 3 Interference and ATC Automation - The digital data carried on Channel 3 provides inputs to the automated enroute ATC system. During the airborne tests the interfered with and clear Channel 3 data were recorded on magnetic tape for subsequent investigations. The main point of interest was to identify what affects, if any, the interfered with Channel 3 data would have on the automated radar data processing program. During a series of tests at the FAA's NAFEC facility in Atlantic City, New Jersey, the recorded Channel 3 data was used as input to the enroute ATC test bed. During the tests the clear and interfered with data were processed by the ATC control program.

Before the test results can be interpreted they must be put into an operational context. Based on information provided by the FAA it was determined that the automated enroute control system is designed for and uses multiple radar data coverage. A scheme where they create a mosaic of the radar is employed that identifies a Primary, Primary Supplemental, and Secondary Supplemental data source for each radar coverage sort box. If a track is established, the tracking algorithm predicts that data should be present in a particular sort box. If no data is present because of interference, loss of coverage or other reasons, the systems' program will automatically search for returns from the Primary Supplemental source and Secondary Supplemental source if necessary. If data from the supplemental sources are available tracking continues normally; if not, tracking will continue but without updates. If a specified number of consecutive updates are lost (the exact number is part of the ARTCC adaptation and can vary between 3 and 6) then the track goes into a "coast" mode. The implications of going in a "coast" mode are that tracks must be reestablished either

manually or automatically. Those aircraft that have a discrete beacon code will be reestablished as a track within approximately two scans (24 sec) after good data is again received. Aircraft that are operating without discrete beacon codes must be reacquired manually by the controller. This could be time consuming if a number of aircraft in this category were present in his area of control responsibility. With this background in mind the results of the 10 kW PN test at NAFEC could be interpreted as follows:

(1) High power 10 kW operation of the airborne SHF terminal can cause a significant loss of data to the ATC control program.

(2) Since the dwell time in the main beam window for perpendicular flight paths was approximately 90 seconds, this could result in having all tracks associated with a particular microwave input go into a "coast" mode with single target coverage.

<u>Channel 2 - 10 kW, Multiple Window, Hardeeville</u> - The interference signal level to the Channel 2 MTI/Normal signal for a 10 kW PN signal from the airborne SHF SATCOM terminal is shown in Figure 87. In this case the airborne SHF SATCOM antenna was directed toward a satellite at 135°W as the aircraft flew through the Hardeeville main beam. This figure shows the PN slot noise at Seales after being transmitted down the microwave link and the desired signal level, measured at Seales. A summary of the results of a comparison between the flight test measurements and the closed system ground tests are shown in Table 19.

This test was designed to test simultaneous coupling to multiple antenna windows and coupling to different sites in the microwave link. Although the results of this test are similar to other 10 kW PN interference

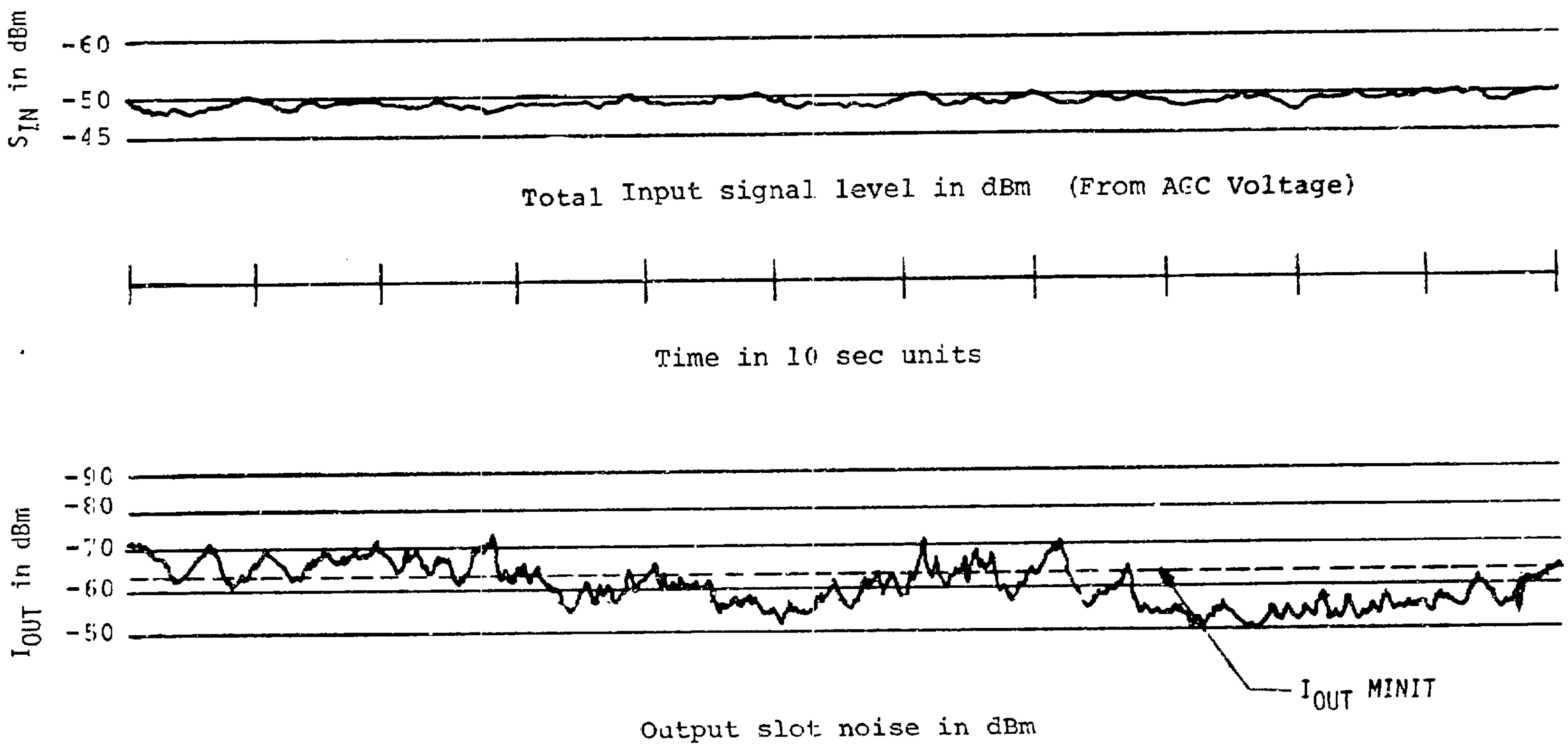


FIGURE 87 CHANNEL 2 SLOT NOISE WITH 10 kW PN INTERFERENCE

runs, the flight configuration was completely different. The flight plan for this test is shown in Figure 88. The actual flight path as recorded by the FAA is shown in Figure 89. This figure shows that the flight was flown close to the specified plan. The flight path was laid out so that it crossed the main beam patterns of Newport and Hardeeville. The coupling could therefore be through Newport, Hardeeville or simultaneously to Seales and Newport or Newport and Hardeeville. No simultaneous coupling between the hops was noted. Therefore, only the coupling to one of the other main beam windows (Hardeeville) was analyzed. For the Hardeeville window, the aircraft was approximately 175 nautical miles from the receiving site and crossed the beam at an angle of approximately 30°. The antenna was aimed at a hypothetical satellite at 135°W to simulate a worst case interference configuration with an antenna elevation of 25°. The aircraft was out of Jacksonville Center and into the Washington ARTCC area for this portion of the test. The interference was received at Hardeeville and relayed down the link to Seales where it was recorded. The diversity combiners were disabled so that monitoring could be made of the PN slot noise at Seales. However, the AGC voltage was not monitored at Hardeeville so that the exact input desired signal level could not be determined. Examination of Figure 87 indicates that the output interference level was about the same as previous 10 kW PN runs and since the hops are designed with the same requirements, the desired signal level from Seales should also be a reasonable estimate for Hardeeville. Table 20 shows that the interference was above the MINIT level for 75 seconds. Figure 90 shows typical Channel 2 PPI display with and without interference. The

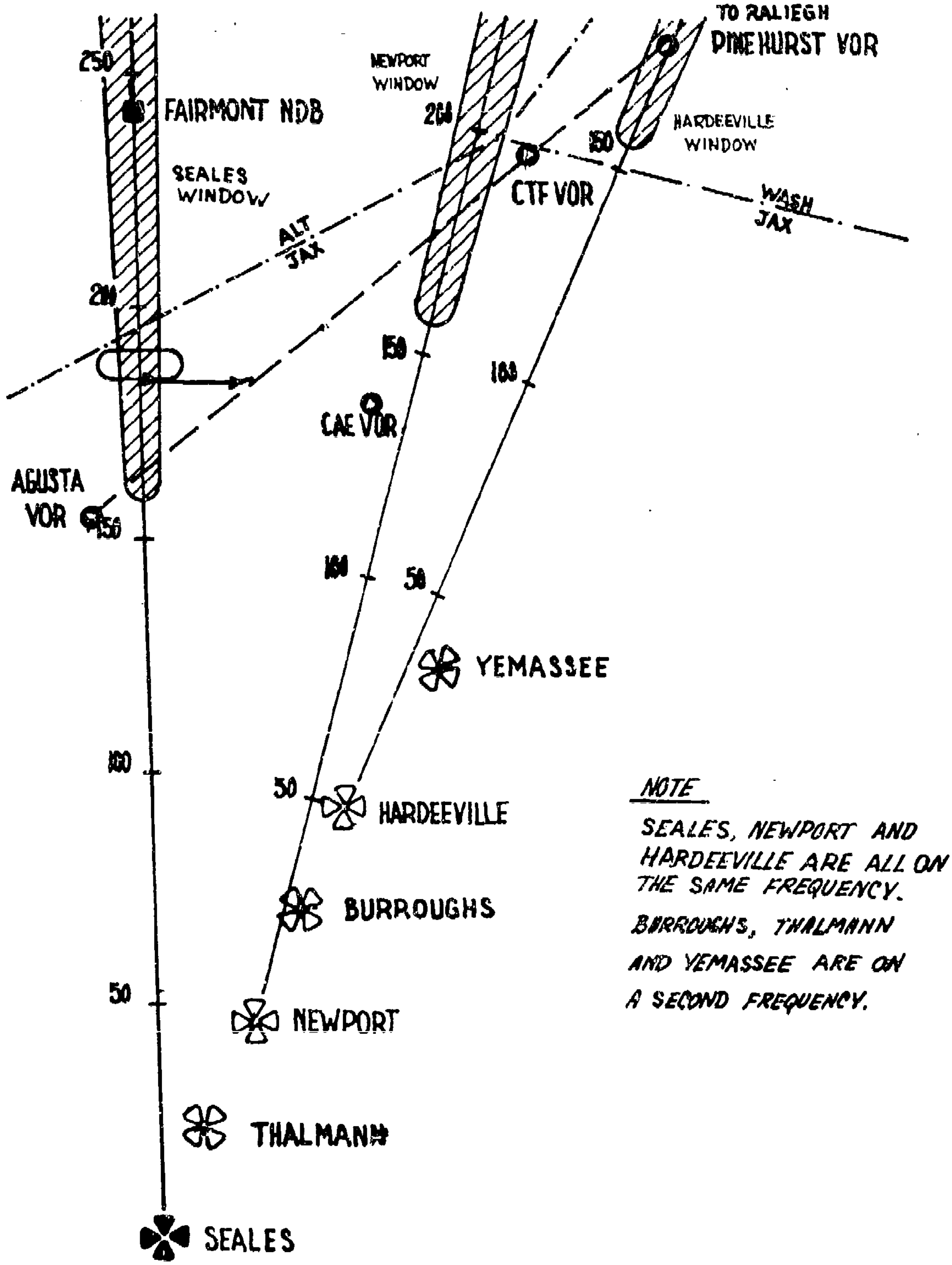


FIGURE 88. MULTIPLE WINDOW FLIGHT PLAN

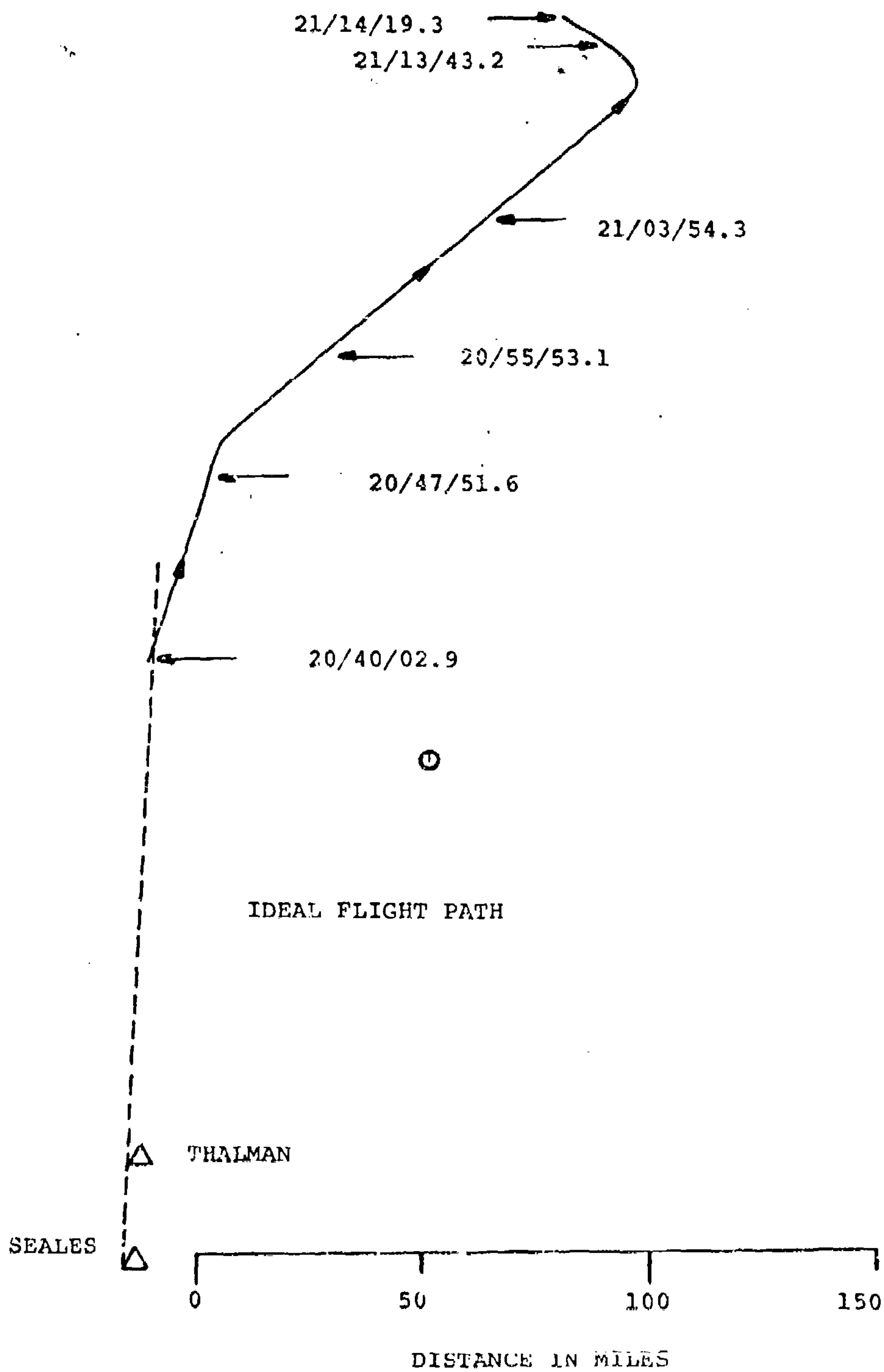
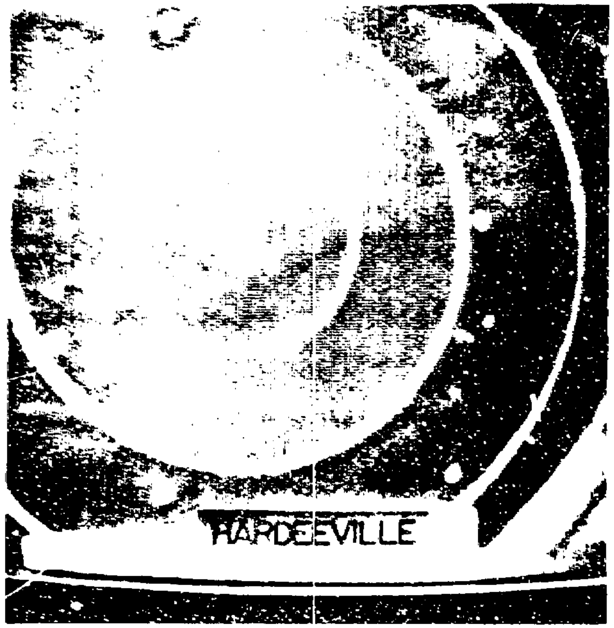


FIGURE 89 FAA RECORDED HARDEEVILLE FLIGHT PATH



Channel 2 PPI Display With No Interference

Channel 2 PPI Display With 10 kW PN Interference

FIGURE 90 CHANNEL 2 PPI DISPLAY WITH AND WITHOUT INTERFERENCE DURING MULTIPLE WINDOW TEST

interference was observed for approximately 90 seconds on the video and showed severe or unacceptable interference conditions. The received interference level differed from the calculated level by 1 dB (using the estimated desired signal level). In general, the interference to this remote site was coupled the same as theoretically predicted.

RML-6 CW ANTENNA TESTS

The RML-6 CW tests at Jacksonville airport were conducted in basically the same manner as those for the RML-4 at Seales, Georgia. The airborne SHF SATCOM transmitter was radiating 10 kW CW power with its antenna at a 10° elevation aimed towards a midpath reflector at Jacksonville Airport.

The RML-6 system tested has a midpath reflector on the link to Cecil Field through the Crawford repeater site. The antenna for the receiver under test is a six foot dish mounted atop the FAA building at Jacksonville Airport at a height of 20 feet. The dish is aimed at a 90° azimuth towards a 10 x 15 foot reflector. The reflector is mounted part way up a water tower 4000 feet away at an elevation of 107 feet. The beam is deflected to an azimuth of 274° toward the Crawford repeater. During the test, the RML-6 transmitter at Crawford was turned off and the receiver at Jacksonville was monitored, measuring, quieting, IF power, and AGC voltage.

A radial flight was flown along the theoretical azimuth of the beam from over the Jacksonville site and Crawford repeater on out to beyond the horizon. No main beam was detected on this flight.

The aircraft was then flown on a course 90° to the orientation of the beam at a distance of approximately 180 nautical miles from the site. Three passes were made through the theoretical beam location. On the second pass,

a very definite beam was observed on the recorders and the received power was higher than the predicted values. All three passes across the beam were within a five mile window centered at 180 nautical miles. A well defined beam was not observed on the first and third passes. The measured beam was extremely narrow and very difficult to locate on subsequent flights.

The theoretical received power is given in Equation 3-6 as:

$$S_{IN} = S_T + G_T + L_{FS1} + G_{REF} + L_{FS2} + G_R - L_L - L_A \qquad (7\text{-}5)$$

where

L_{FS1} = free space propagation loss (aircraft to reflector, 161 dB)

G_{REF} = reflector two way gain, 102.5 dB

L_{FS2} = free space propagation loss (reflector to RML, 112 dB)

L_L = line loss, 1.0 dB

$$G_{REF} = \frac{\pi A \cos x}{\lambda^2} \qquad (7\text{-}6)$$

where

A = area of reflector, 150 sq ft

x = included angle between incident and reflected beam, 1°

λ = wave length, 0.13 ft

Therefore, the received power is found to be

$$P_R = 70 \text{ dBm} - 1 \text{ dB} - 161 \text{ dB} + 102.5 \text{ dB} - 112 \text{ dB} + 40.4 - 2 \text{ dB}$$
$$= -64.1 \text{ dBm} \qquad (7\text{-}7)$$

The peak measured power was -54 dBm. The measured and the theoretical values differ by more than 6 dB which is the amount of reinforcement possible due to perfect multipath propagation. Therefore, the results of this measurement is outside the expected range of possible error.

However, other characteristics of the measured beam tend to indicate some other phenomenon is occurring rather than simple multipath.

Figure 91 is a plot of the actual recorded received signal for the second pass through the beam. Based upon the beamwidth (in seconds) and the reported aircraft ground speed, the beamwidth was computed to be 0.23 degrees.

The theoretical beamwidth of a 10 x 15 foot reflector is approximately 0.65 degrees.[18] If multipath alone were causing the increased signal level, the expected trace on the recorder would be a series of peaks and troughs occurring over the entire beamwidth of 0.65 degrees. The average value for the signal should be close to that predicted. This is clearly not the case. The 0.65 degree beam would be 18 seconds wide. All signals in the region are greater than 20 dB down with the exception of a single narrow spike which is located very close to the theoretical position of the first sidelobe of a pattern of a 0.23 degree main beam antenna.

A plausible explanation for this discrepancy is that this beam is the result of illuminating the entire water tower. The exact dimensions of the water tower are not known. It appears to be approximately 30 feet in diameter. This closely approximates the size aperture required to produce a 0.2 degree beamwidth. Apparently then the pattern observed is the result of illuminating the entire, almost spherically shaped water tower, and the higher gain pattern from this effectively masks the pattern from the reflector alone.

Concern might be expressed over the existence of the higher antenna gains which are essentially impossible to account for in a theoretical analysis. However, the remainder of the testing confirms the real effect

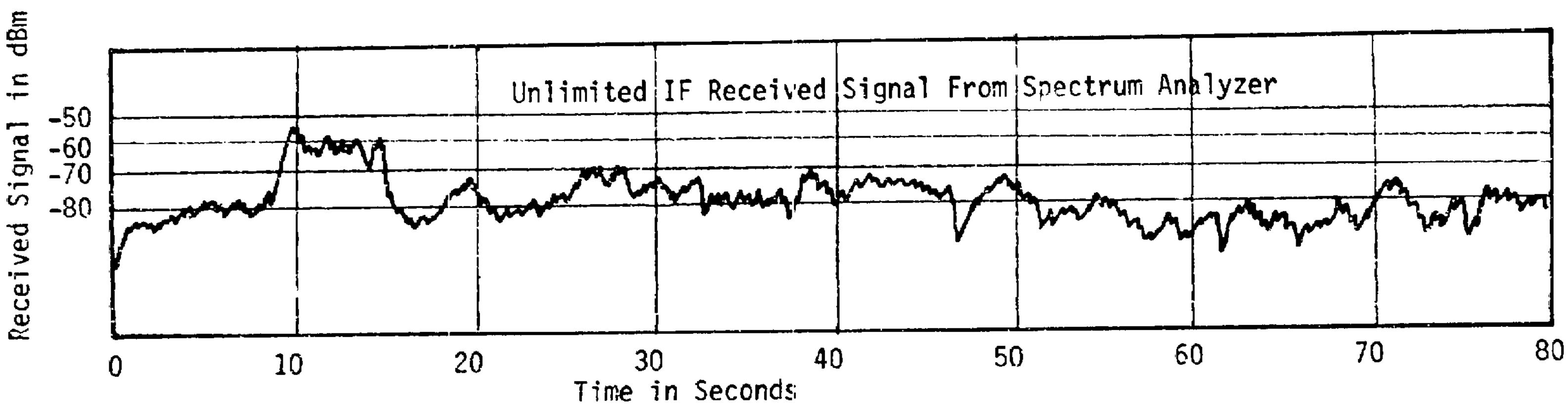


FIGURE 91 RECEIVED SIGNAL DURING CW ORBIT ACROSS RML-6 REFLECTOR BEAM

of these narrow beams. Three hours of continuous flying out in the vicinity of the beam and making a concerted effort to locate it resulted in duplicating the maximum signal level only twice. The narrower these beams get, the much lower the probability of encounter becomes.

The effect of coupling into the primary beam of the microwave dish was also investigated. Due to air space restrictions, the aircraft could not operate where it would normally intercept this beam at 24,000 feet. The intercept instead occurred at an altitude of 10,000 feet at a distance of 35 miles. The beam was detected and appeared to suffer little distortion due to the blockage by the water tower as shown in Figure 92. The received interference power was measured as -40 dBm. The theoretical power can be computed from Equation 3-6 to be:

$$S_{IN} = S_T + G_T - L_{FS} + G_R - L_S - L_A$$

$$= 70 - 1 - 146 + 40.4 - 1 - 2 = -40.4 \text{ dBm} \qquad (7\text{-}8)$$

These values are well within the measurement error and verify the fact that primary as well as reflected beams must be considered when assessing the potential interference to such systems.

RML-6 PN DEGRADATION TESTS

The RML-6 PN flight tests were limited to an examination of the interference potential to the MTI/Normal channel since this was the most susceptible channel. Previous sections have discussed the fact that the interference window for the RML-6 at Jacksonville Airport was narrower than normally had been encountered since the main beam was a reflected and not a direct beam. In addition the degradation to the MTI/Normal on the Beacon Channel was being observed on a typical PPI with a short persistence time. The combination of these two facts made it difficult to observe interference on the PPI. Only one noticeable interference event occurred for this condition.

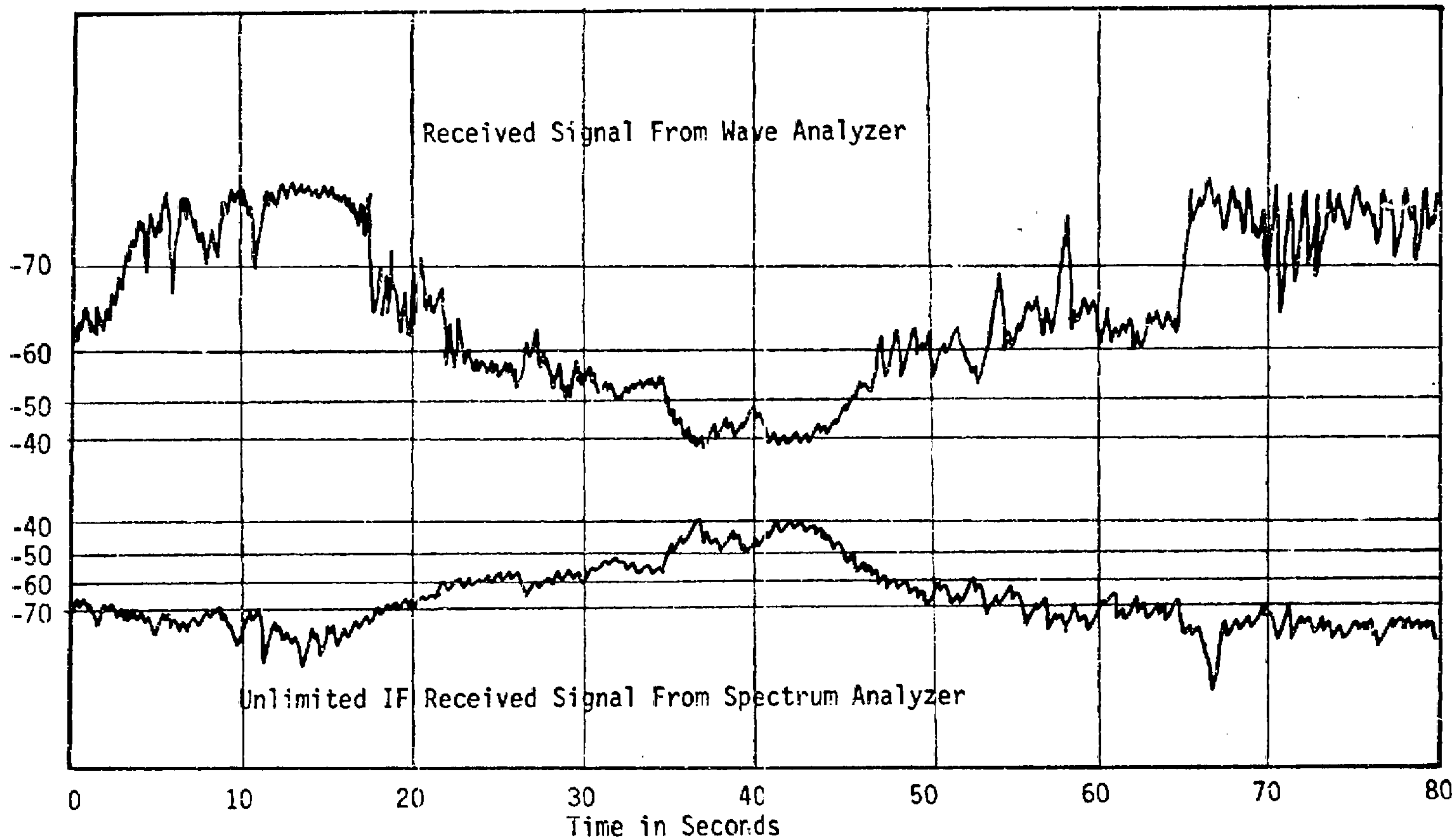


FIGURE 92 RECEIVED SIGNAL DURING CW ORBIT ACROSS RML-6 DISH MAIN BEAM

The interference effect to the MTI/Normal signal for the case of a 10 kW PN signal from the airborne SHF SATCOM antenna looking at the RML-6 reflector at Jacksonville is indicated in Figure 93. This figure shows the PN slot noise and the desired signal level. A summary of the results of a comparison between the flight test measurements and the closed system ground tests are shown in Table 19. The time that the interference was above the -50 dB level was very short and was effectively only two seconds. A small burst of interference was noted on the PPI at this time. The average peak interference level (neglecting one major peak) differed from the calculated value by 4 dB. The variation between these peaks and their corresponding lows indicates a different degradation result than the previously discussed RML-4 cases. The RML-4 varied about 10 dB while Figure 93 indicates a variation of 25 dB.

This larger variation resulted in the interference level dropping below the MINIT level for at least half of what appears to be the main window. This was probably caused by the narrow reflected beam and reduced the degradation that was experienced by the RML-6 receiver.

Summary of FAA Flight Test Measurements - A summary of the significant results of the FAA flight tests are:

RML-4 Results

1. Significant degradation to Channels 1, 2 and 3 was experienced from the 10 kW PN signal for the case of an unfaded desired signal.

2. The effect of Channel 3 lost messages on the ATC automation is noticeable on the controller's display with single radar coverage. It appears that when multiple coverage is available, no operational degradation to the ATC system should exist because of interference to the Channel 3 inputs. However, multiple coverage does not exist in enough of the CONUS to have this technique become a general solution to the problem.

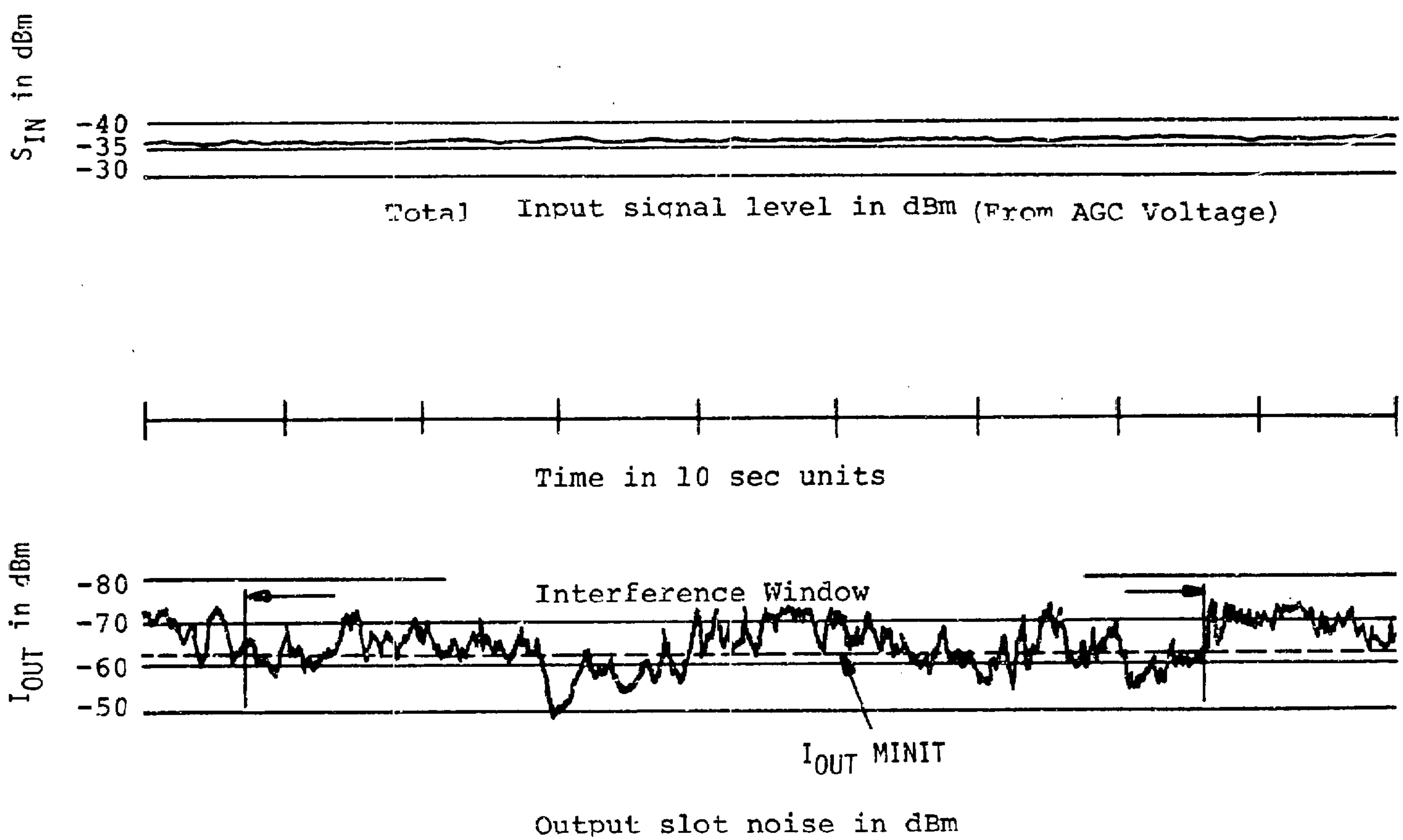


FIGURE 93 RML-6 MTI/NORMAL SLOT NOISE WITH 10 kW PN INTERFERENCE

3. No degradation to Channels 1 and 3 (and 2 theoretically) was experienced from a 1 kW PN signal for the case of an unfaded desired signal. (NOTE: This does not mean that 1 kW is a satisfactory operating PN signal level since fading statistics were not considered in the flight test; see the section on probability considerations for a consideration of this factor.)

4. The closed system (S/I) protection ratios correctly predicted the open system degradation effects.

5. The combination antenna gain and loss values were accurate with an average difference of +1.3 dB between measured and theoretical values. This tends to confirm that the front porch of the aircraft antenna is -1 dBi as measured in the AFAL tests.

6. The average time of the noticeable interference effects for a perpendicular beam crossing was 90 seconds. This corresponds to antenna window angle of approximately 3.4° (approximately twice the 3 dB antenna beamwidth of a 39 dB antenna).

7. The analysis procedure and the parameters used in the analysis (antenna gain, propagation loss, S/I criteria, etc.) are correct.

8. The performance degradation to a multichannel FM system from PN interference is approximately the same as from gaussian noise.

RML-6 Results

1. The measured RML-6 reflector beamwidth was a very narrow 0.23 degrees.

2. Both primary and reflected beams were encountered for the RML-6 system.

PROBABILITY CONSIDERATION OF RANDOM FLIGHT PATHS

In order to determine performance levels of microwave links which are subject to airborne platform interference, it is necessary to consider the statistics of both the interfering and the desired signal. This problem was initially discussed in Reference 1. The following summarizes the analysis contained in the reference and determines the probability or time that the SHF SATCOM aircraft can be in a given area so as to not change the design outage probabilities of a microwave link.

To simplify the derivation of a digital or analog microwave system statistical performance equation, it was assumed that the desired and undesired signal can exist in two states. That is, the desired signal can be considered to exist in a faded and an unfaded state with a probability given by:

$P_{S,\ NO\ FADE}$ = Probability of desired signal not being in Fade (relates to the median signal condition).

$P'_{S,\ FADE}$ = Probability of desired signal fading to a specified performance level (fade margin).

$P''_{S,\ FADE}$ = Probability of desired signal fading to the interference level.

The airborne platform generates a source of interference which, in the most general case, is only present for random periods of time. Hence, the state of the interference signals can be defined with probability levels given by:

P_I = Probability of the median undesired (interfering) signal being present at the microwave receiver.

$1 - P_I$ = Probability of the median (non faded) undesired signal not being present at the microwave receiver.

The interference is considered to exist only in the median signal level condition. If fading of the interference signal is considered, an additional set of probability terms would be required; however, as indicated in Reference 1, they would have little or no impact on the final interference assessment.

For each desired and interfering signal probability state, a corresponding system error probability can be defined. Since there are four states, the resultant total system Digital Error Probability (P_E) or Analog Performance (PER) can be expressed by:

$$
\begin{aligned}
P_E = {} & P'_{S,\ FADE} \times (1 - P_I) \times P_{E,\ FADE} \\
& + P''_{S,\ FADE} \times P_I \times P_{E/FADE\ +\ I} \\
& + P_{S,\ NO\ FADE} \times (1 - P_I) \times P_{E/NO\ FADE} \qquad \text{(Negligible term)} \\
& + P_{S,\ NO\ FADE} \times P_I \times P_{E/NO\ FADE\ +\ I}
\end{aligned}
$$

where

$P_{E/FADE}$	= Probability of error in the system when the desired signal is faded
$P_{E/NO\ FADE}$	= Probability of error in the system when the desired signal is not faded
$P_{E/FADE\ +\ I}$	= Probability of error in the system when the desired signal is faded and the interference is present
$P_{E/NO\ FADE\ +\ I}$	= Probability of error in the system when the desired signal is not faded and the interference is present

and Analog Performance can be expressed by:

$$
\begin{aligned}
PER = {} & P'_{S,\ FADE} \times (1 - P_I) \times PER/FADE \\
& + P''_{S,\ FADE} \times P_I \times PER/FADE + I \\
& + P_{S,\ NO\ FADE} \times (1 - P_I) \times PER/NO\ FADE \qquad \text{(Negligible term)} \\
& + P_{S,\ NO\ FADE} \times P_I \times PER/NO\ FADE + I \qquad (7\text{-}10)
\end{aligned}
$$

where

PER/FADE	=	Performance in appropriate units (i.e., S/N, RMS error, etc.) in the system when the desired signal is faded
PER/NO FADE	=	Performance in appropriate units in the system when the desired signal is not faded
PER/FADE + I	=	Performance in appropriate units in the system when the desired signal is faded and the interference is present
PER/NO FADE + I	=	Performance in appropriate units in the system when the desired signal is not faded and the interference is present

The groups of terms that evaluate the error probability (P_E) or analog performance (PER) for the non-faded desired signal and no interference state is typically negligible relative to the other terms. For example, the typical error probability associated with a non-faded or median signal-to-noise (S/N) of 50 dB is approximately 10^{-64} (this can be obtained from an extrapolation of the curve in Figure 94) for the case of gaussian noise. It should be noted that the use of gaussian noise error curve is not exact for low (S/N) ratios in FM systems since it does not consider FM "click" or "pop" noise, but should be a good estimate for high (S/N) ratios. For the case presently being considered, the 10^{-64} is such a small number that the product of this and $P_{S,\ NO\ FADE}$ (.5) and $(1 - P_I)$ [(≈1)] is very small relative to the other terms and consequently will be neglected. Therefore, the performance equation has three basic parts that should be considered in more detail. The P_S' and P_S'' terms should actually consider the distribution of the fading of the desired signal. Reference 1 discusses examples which indicate that representative values for the probability of error can be obtained when only the probabilities associated with signal fade are considered (see

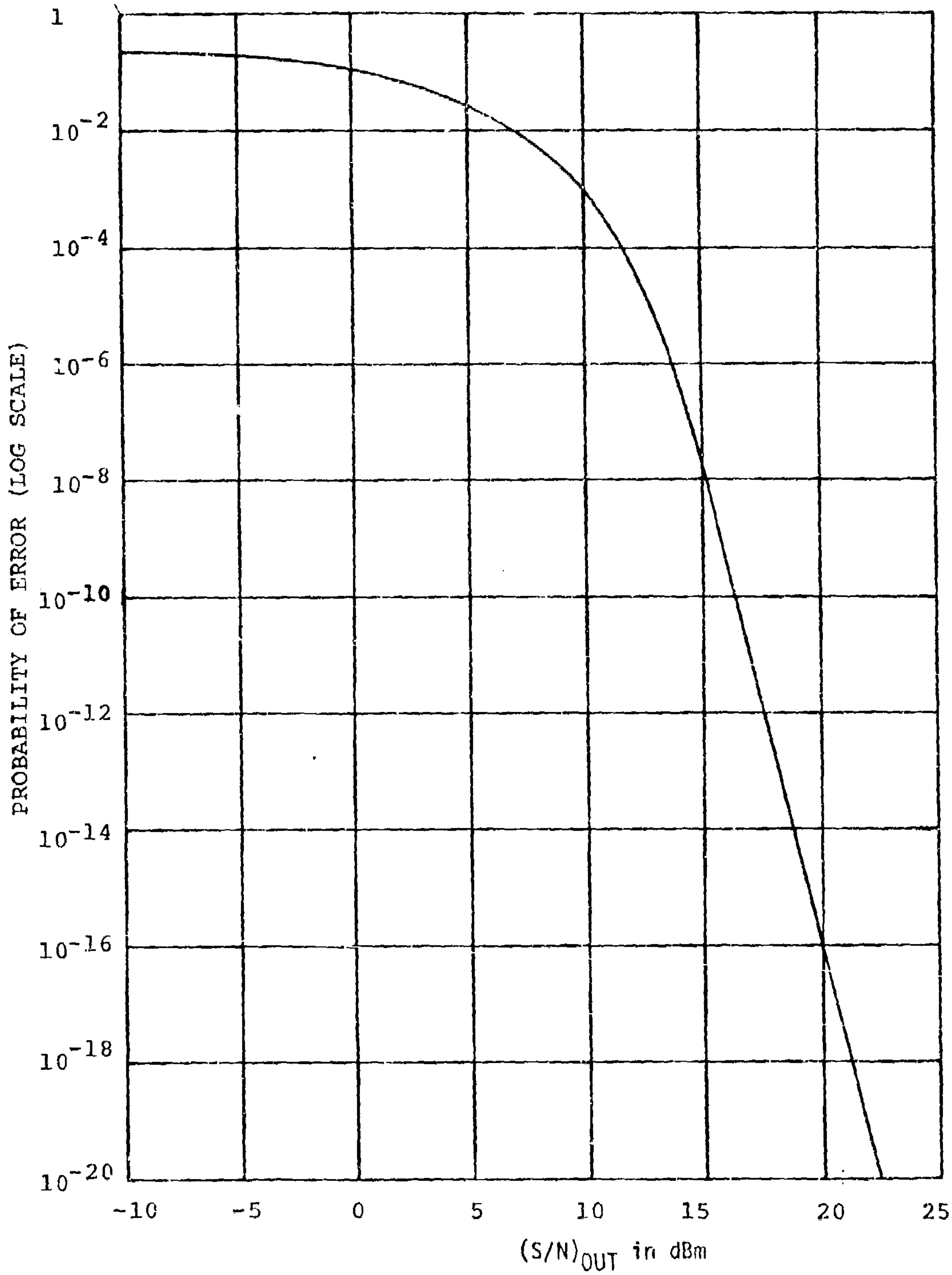


FIGURE 94 PROBABILITY OF ERROR VERSUS SIGNAL- TO-GAUSSIAN NOISE

Figure 95). That is, for the $P_{S,\ FADE}$ distribution, only the term involving the probability of fading to the specified performance level (i.e., typically the median output (S/N) minus the fade margin) need be evaluated. For the fading probability involving the presence of the interfering signal, the $P''_{S,\ FADE}$ term is obtained by calculating the probability that the signal will fade to the interference level (i.e., the specified S/I ratio). The $P_{S,\ NO\ FADE}$ term is the median value and therefore equal to a value of 0.5.

The system error probability terms of Equation 7-9 are evaluated for the (S/N) levels that correspond to the indicated probability states. The $P_{E/FADE}$ is the error probability given that the desired signal has faded. The $P_{E/FADE\ +\ I}$ term is evaluated at the ideal capture level of the receiver (i.e., $(S/I)_{IN}$ = 0 dB) and is given as 0.5 for an ideal receiver. It should be noted that this value could actually vary between 0.5 and 1 for a particular receiver structure. This possible variation would not significantly change the performance levels. The final $P_{E/NO\ FADE\ +\ I}$ term is approximately given by the probability of obtaining a (S/N) level (from Figure 94) that corresponds to the specified (S/I) ratio.

The probability of interference term (P_I) is now fixed for a particular operational scenario or could be varied along with assumed (S/I) ratios to obtain a parametric range of trade-off values. If a range of trade-off values are being examined and desired performance levels cannot be changed, the product of $P_{S,\ FADE}$ and P_I should be generally equal to or less than the probability of fading to the noise capture level (i.e., S/N = 0 dB). In addition to this constraint, the product of P_I and $P_{E/NO\ FADE\ +\ I}$ should be examined to determine if it is equal to or less than the performance

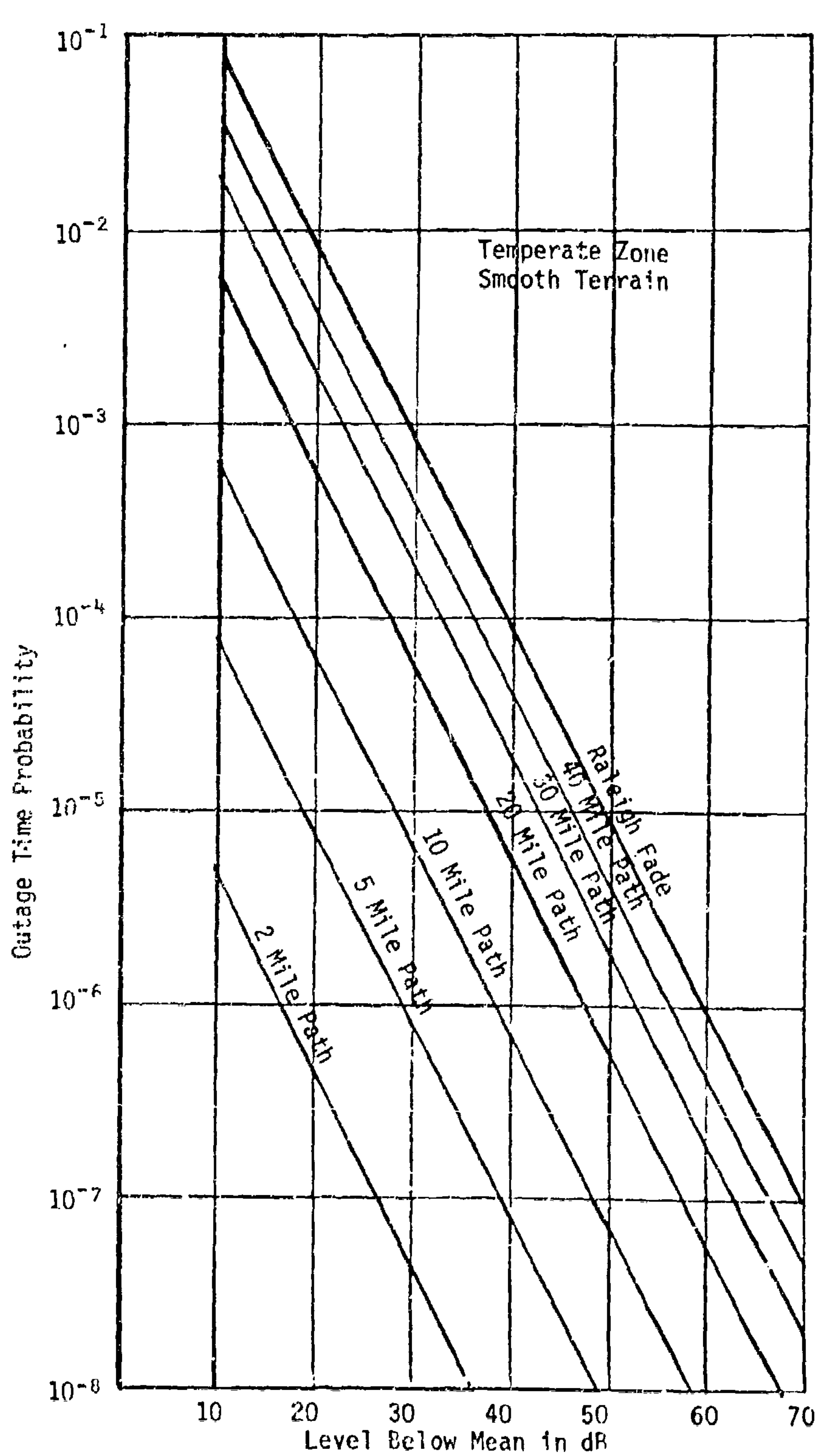


FIGURE 95 OUTAGE TIME VERSUS FADE MARGIN

with no interference present (given by $P_{S, FADE} \times P_{E/FADE}$). The total probability of error (P_E) or analog performance (PER) is given by the sum of the three terms in Equation 7-9 or 7-10.

For the analog case, it is not possible to simply multiply all the terms together in Equation 7-10 and obtain a total system measure. Instead, there are three statements which are equivalent to saying that there is a probability of having a given (S/N) ratio. Although, in general, this makes the formulation more difficult, the same general procedure that was outlined for the digital system can be applied to the analog system to determine trade-off (S/I) and P_I levels.

For the FAA RML-4 case presently being considered Table 15 indicated that the worst case processing gain was -8 dB. Table 19 indicated that the corresponding protection ratio for Channel 2 is 15 dB. The corresponding inband (S/I) ratio is 20 dB, i.e., [15 dB + 10 log (40 MHz/15 MHz)]. Substituting these values in Equation 7-10 and using the criteria that the interference terms should be one-half of the left hand design performance term to be negligible, we obtain for Channel 2 that:

$$\begin{aligned} PER &= (3 \times 10^{-3})(1)(\text{for } 12 \text{ dB}) + (2 \times 10^{-3})(3 \times 10^{-3})(\text{for } 0 \text{ dB}) \\ &\quad + (.5)(3 \times 10^{-3})(\text{for } 12 \text{ dB}) \\ &\approx 4.5 \times 10^{-3} \quad (\text{for } 12 \text{ dB}) \end{aligned} \tag{7-11}$$

where

$(S/I)_{IN}$ = 20 dB

PG = -8 dB Channel 2

FM = 30 dB

The right hand expression, which is controlled by the median desired signal term, is the predominant interference term in the expression. The performance

level in the left hand term, which is due to the fading of the desired signal, without interference, is therefore set equal to the right hand term.

For Channel 5 we find that for the case of $(S/I)_{IN}$ = 15 dB that:

$$PER = (9 \times 10^{-4})(1)(\text{for } 15\text{ dB}) + (6 \times 10^{-3})(9 \times 10^{-4})(\text{for } 0\text{ dB}) + (.5)(9 \times 10^{-4})(\text{for } 15\text{ dB}) \approx 13.5 \times 10^{-4} \quad (\text{for } 15\text{ dB}) \tag{7-12}$$

where

$(S/I)_{IN}$ = 15 dB
PG = 0 dB Channel 5
FM = 23 dB

For the case of $(S/I)_{IN}$ = 25 dB, we find that:

$$PER = (9 \times 10^{-3})(1)(\text{for } 25\text{ dB}) + (6 \times 10^{-4})(9 \times 10^{-3})(\text{for } 0\text{ dB}) + (.5)(9 \times 10^{-3})(\text{for } 25\text{ dB}) \approx 13.5 \times 10^{-3} \quad (\text{for } 25\text{ dB}) \tag{7-13}$$

where

$(S/I)_{IN}$ = 25 dB
PG = 0 dB Channel 5
FM = 23 dB

The minutes per day flight time [or equivalently the interference probability (P_I)] values summarized in Table 21 are based upon a criteria of negligible increase in the system outage time. The examples above are given for a 50% increase (i.e., 9×10^{-4} to 13.5×10^{-4}). Different values could be similarly derived for other increases. The minutes per day flight times

are the maximum that can be allowed without increasing the outage time beyond the specified 50% increase. In any given area, the flight scenario may be such that the actual flight time in that area is considerably less than the maximum value. This would consequently result in a much smaller increase in the outage time than the 50% value specified. Insufficient information was available to evaluate the actual flight time in any given area so that only the maximum time has been given.

In summary, it is recommended that the actual values of P_I or the flight time of the airborne SHF SATCOM terminal be equal to or less than shown in Table 21 so as to negligibly increase the design outage times of the links.

ATTIC ANALYSIS

General - In order to examine potential interference problems to a complete microwave system, a computer program was developed which can be used to examine Airborne Terminal-to-Terrestrial terminal Interference Calculations (ATTIC). This program computes the level of interference coupling to all the microwave receivers in an environment and then determines (S/I) protection contours around the microwave receivers corresponding to these interference levels. This program is described in greater detail in Appendix C and in Reference 28. For the present problem the ATTIC program will be used to examine (S/I) contours around Jacksonville for the 8045 MHz test frequency and the total U.S. at a typical airborne SHF SATCOM system operating frequency of 8240 and 8150 MHz.

Jacksonville ATTIC Analysis - The previous section examined measured performance degradation to particular RML-4 and RML-6 links in the Jacksonville

TABLE 21

RECOMMENDED INTERFERENCE PROBABILITY VALUES

CHANNEL	(S/I) Inband in dB	P_I^*	FLIGHT TIME (minutes/day)
Channel 2 (worst case)	20	3×10^{-3}	4.4
Channel 5	15	9×10^{-4}	1.3
	25	9×10^{-3}	13

*P_I indicates the maximum probability that an interference source can be present.

area. A general conclusion that was reached from an examination of these measurements was that the analysis procedure and the characteristics used in the analysis (antenna gain, propagation loss, S/I criteria, etc.) were correct. Therefore, as a starting point for a system examination of the total U.S. FAA environment, the Jacksonville area links will be examined using the system characteristics contained in the Government Master File (GMF) and the ATTIC program. For the 8045 MHz test frequency the general RML characteristics are obtained from the GMF. The airborne SHF SATCOM system characteristics utilized are those presented in Appendix B. A typical computer (S/I) contour plot is shown in Figure 96 for the 8045 MHz test frequency and a 15 dB (S/I) criterion. The program simulated that the airborne SHF SATCOM system was transmitting 10 kW of power to a satellite at 13°W. The 15 dB (S/I) criterion signifies the Minimum Interference Threshold (MINIT) for Channel 3 and Channel 5 (see Table 18). The (S/I) ratio is the rati of the median desired to an inband interference level and represents unfaded signal levels. The 8045 MHz corresponds to the center frequency of Channel 4 at the test site (Seales, Georgia) and is being used to show typical computer protection ratio contours. Figure 96 shows main beam and sidelobe protection contours. The sidelobe contours are caused by coupling between the sidelobes of the antennas and only occur near the receiving site (denoted by unprimed letters). The aircraft antenna coupling model used in the ATTIC program does not take into account aircraft shielding to an antenna directly below the aircraft. The flight test results previously described indicate that the contours near the site would not really exist. The main beam contours (denoted by primed letters) are caused by coupling between the main beam of the microwave and the sidelobe of the aircraft. The main beam ATTIC

patterns appear separated into smaller areas in certain parts of the main beam patterns. See for example, the Hardeeville beam labeled C . The beam breakup is a resolution problem caused by having insufficient sample points in the main beam area to adequately define the beam. The beam is actually continuous in this area and is defined by a contour surrounding the smaller zones. The main beam pattern generally occurs from approximately 150 to 250 miles from the receiving site and has a width slightly wider than the beamwidth of the microwave antenna. Appendix C further discusses the ATTIC program and the resulting shape of the protection ratio contours.

The path of the aircraft flown in the flight test and previously discussed in Figure 88 for the Multiple Window, Hardeeville test is also shown in Figure 96. This path shows that unacceptable interference should have been received since the aircraft crossed the main beam protection contours. The previous discussion of the flight test measurements showed that this is exactly what happened. The ATTIC plots, therefore, for steady state signal conditions are a good indicator of potential interference problems. In addition to the examination of critical MINIT (S/I) contours, it is also desired to consider higher level protection ratio which essentially consider various degrees of fade margins for the desired signal. The multi-level contours of 15, 20, 25 and 30 dB for the same set of conditions previously discussed is shown in Figure 97. Since the (S/I) contours were plotted for median or unfaded signal levels, the 30 dB contour could represent that contour required for protection when the desired signal fades 15 dB. The increase in the areas required for this contour is quite large and essentially covers the whole area above Jacksonville. The

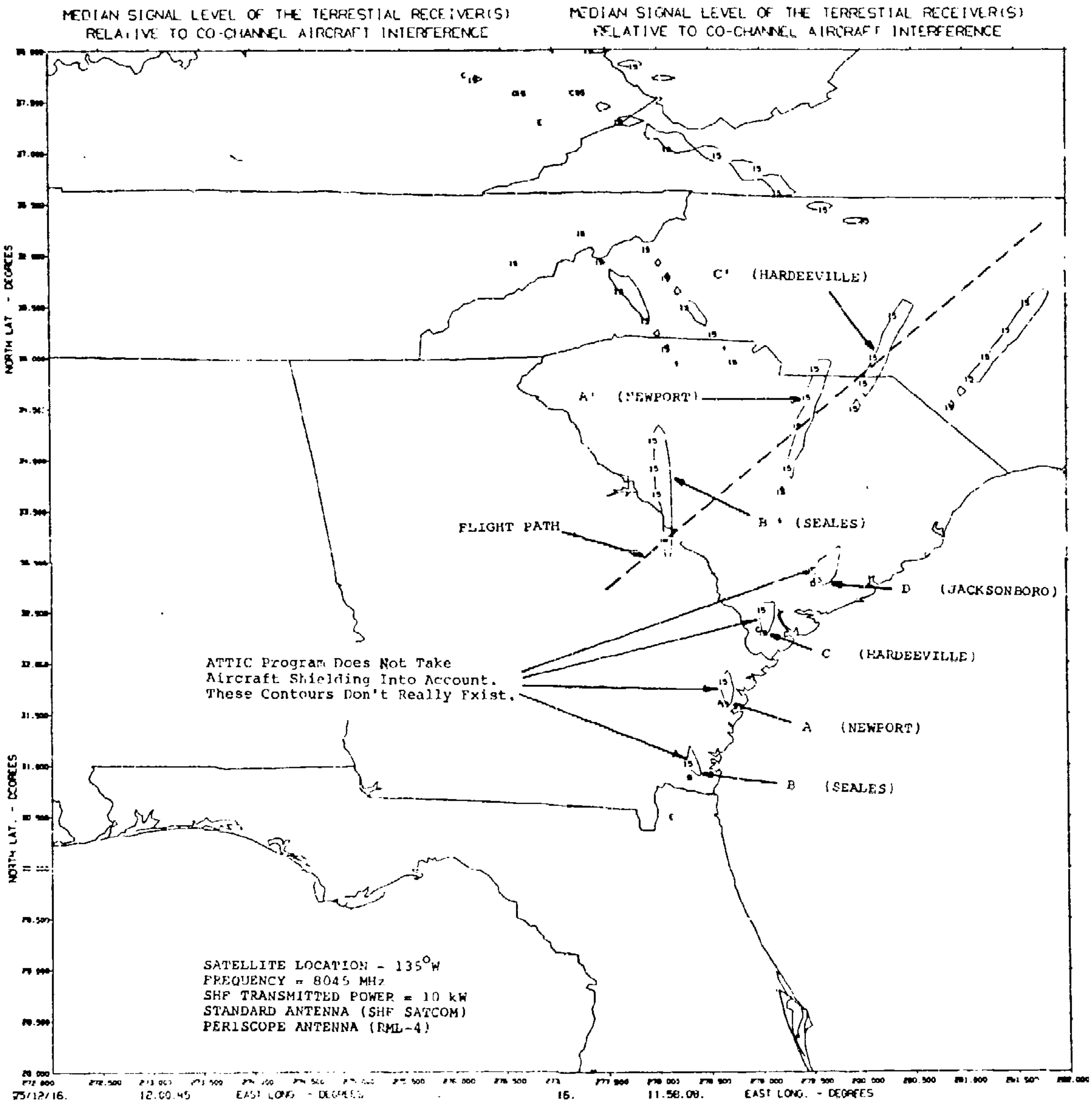


FIGURE 96 ATTIC PLOT OF 15 dB CONTOURS FOR 8045 MHz

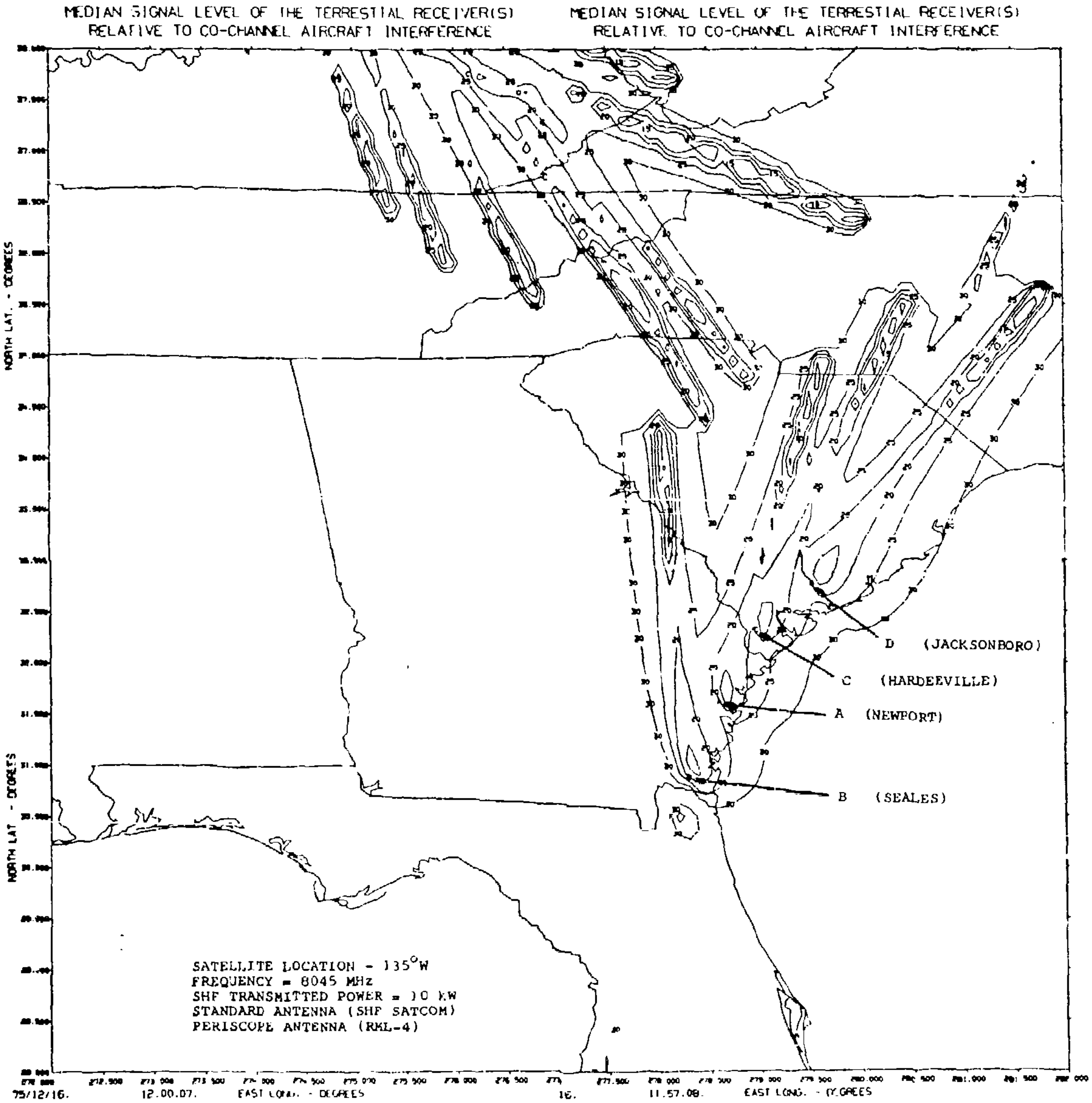


FIGURE 97 ATTIC PLOT OF MULTIPLE CONTOURS FOR 8045 MHz

next section will discuss the probability associated with these multi-level contours.

U.S. ATTIC Analysis - The next step is to examine for a typical airborne SHF SATCOM system operational frequency protection contour required for the entire United States. Figure 98 shows the 15 dB, 25 dB and 35 dB nested contours for the entire U.S. at a frequency of 8240 MHz. The program simulated that the airborne SHF SATCOM system was transmitting 10 kW of power to a satellite located at 135°W. Figure 99 shows the same set of nested contours for the eastern portion of the U.S. and a satellite location of 13°W. Figures 100 and 101 show similar contours for a frequency of 8150 MHz. The frequencies of 8150 and 8240 MHz were previously discussed in SECTION IV as being planned transmission frequencies for the narrow beam to narrow beam and narrow beam to earth coverage satellite transmission modes. The 135°W satellite location can be used to cover the entire U.S. or the western portion of the U.S. The 13°W satellite location can only be used for the eastern portion of the U.S. Both satellite location maps are shown because the difference in the pointing angle of the aircraft to the satellite causes a maximum 12 dB difference in antenna coupling to the microwave receiver. That is, when the aircraft antenna is pointing at 13°W, the coupling from the aircraft antenna is from the -1 dBi front porch shown in Figure 3 and when the aircraft antenna is pointing at 135°W, the coupling could be from the back of the antenna at a level of -13 dBi. This is particularly evident by examining the two contour plots and noting the increase in the size of the contours for the same (S/I) ratio.

FIGURES 98, 99, 100, AND 101 ARE OVERSIZE. THEY ARE LOCATED IN THE BACK OF THE REPORT.

The 135°W satellite map shows that for the 8240 MHz frequency, five areas in the U.S. are interfered with. The interfered with areas are Salt Lake City, Kansas City, Memphis, Atlanta and Washington. For each of these areas both main beam and sidelobe protection ratio contours are shown. The area inside the 15 dB contours (the shaded areas) should be avoided with the aircraft. That is, if the aircraft flies through the 15 dB contours, unacceptable interference will be created. The 15 dB MINIT criterion has been chosen for the 8240 MHz operation frequency because this is the criterion for Channel 5 and this frequency can only interfere with Channel 5. This is shown in the FAA frequency plan, Table 12. Table 19 summarized that the MINIT for Channel 5 was 10 dB. Since the ATTIC plots are shown for inband (S/I) ratios, this corresponds to an inband (S/I) of 15 dB $[10 + 10 \log \frac{(40 \text{ MHz})}{(15 \text{ MHz})}]$.

The 15 dB contours shown in Figure 98 represent considerable areas that must be avoided. The areas are also reasonably scattered across the U.S. so that not one overall area can be avoided. If it is assumed that it is desired to fly through the 25 dB contour and cause only negligible degradation to the system, the number of flights that are flown must be limited. In particular the Interference Probability Section showed that for the 25 dB contour, 13 minutes per day of flight could be flown through this contour. This means that although once a day a typical 25 dB contour could be crossed in this period of time, a flight could not be flown through a long path of the contour. A typical example is shown in the Salt Lake City region by the dotted flight paths A or B. The time for A and B is approximately 60 minutes for an aircraft flying 360 nautical miles/hour. It can be reasonably

concluded, therefore, that one needs to avoid an area approximately bounded by the 25 dB contours (the length of the 35 dB contours is in most cases about the same as the 25 dB contours).

Microwave System Considerations - The previous section analyzed the results of the ATTIC program for particular FAA and airborne SHF SATCOM system configurations. The system parameters that should mainly be considered over a general parametric range are an operating frequency between 7.9 and 8.4 GHz and a transmitter power between 10 kW and 100W.

7.9 to 8.4 GHz Operating Frequency Range - It is desired to examine potential airborne SHF SATCOM system operating frequencies between 7.9 and 8.4 GHz. A previous report by ECAC[2] generated a number of microwave receiver antenna pointing angle plots which showed that the average density of FAA microwave receivers across the U.S. was approximately the same no matter which frequency was chosen for the SHF SATCOM transmitter. Therefore, although particular frequency assignments will determine somewhat different protection contours, the general conclusions will remain the same as previously discussed in the U.S. ATTIC Analysis section. Table 12 shows that the 8.240 GHz frequency could interfere with frequency groups F and J of Channel 5. The frequency 8.150 GHz could potentially interfere with Channel 5 of frequency group E, and Channel 4 of frequency groups H and J. Channel 4 is a spare channel for Channels 1 to 3. Channel 5 carries information in the reverse direction (i.e., from the control center to the radar). The main function of Channel 5 is to carry voice signals, remote switching tones (both Channels 5 and 6 must be interfered with at the same time to interfere with this information), and a sensing signal which determines if the signal levels are operating according to specifications.

The frequencies between 7.900 GHz and 8.025 could potentially interfere with channels 2 and 3. For a particular example, the frequency 7.965 GHz could potentially interfere with frequency groups F, G and K of Channel 3.

10 kW to 100W SHF SATCOM Transmitter Power - It is generally desired to examine the interference effects from the airborne SHF SATCOM transmitter powers from 10 kW to 100W or lower, if required. From the previous ATTIC plots shown in Figure 98, it is apparent that for the critical case of the 15 dB (S/I) criterion and 10 kW transmitted power main beam and sidelobe restricted areas are encountered. Figures 102, 103 and 104 show the 15 dB, 10 dB and 5 dB contours, respectively, for the typical case of Salt Lake City. The 5 dB figure shows that the contours have been reduced to a negligible area. Since the 5 dB (S/I) contour for 10 kW transmitted power is the same as a 15 dB (S/I) contour for 1 kW transmitted power, it can be concluded that the power should be reduced to 1 kW. This would mean that for the median signal condition, one would not encounter severe problems operating at 1 kW. However, it would not mean that the 25 dB contour should not be protected with a given probability level. In particular, it can be readily determined that the heavy shaded areas in Figure 98 should now be protected with a P_I value of 9×10^{-3} (13 minutes/day). Smooth protection contours should now be drawn around the shaded area. This area is now considerably smaller than the previous 25 dB contour area shown in the 8.240 GHz ATTIC plot. This would allow approximately one flight per day along the direction of the main beam.

A sketch of possible flight paths for the airborne SHF SATCOM system transmitting between 10 kW and 100W is summarized in Figure 105.

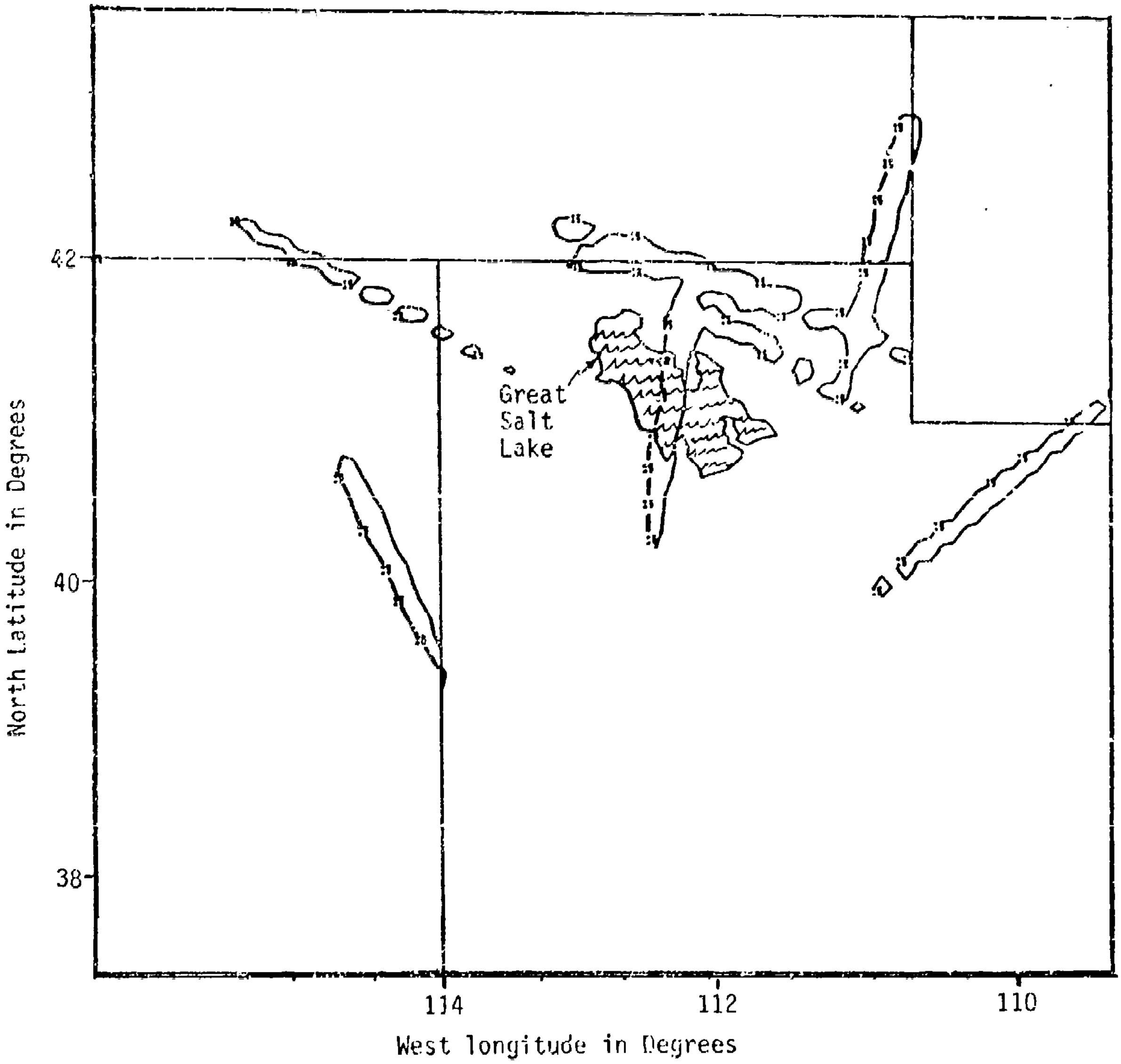


FIGURE 102 15 dB SALT LAKE CITY PROTECTION RATIO CONTOUR

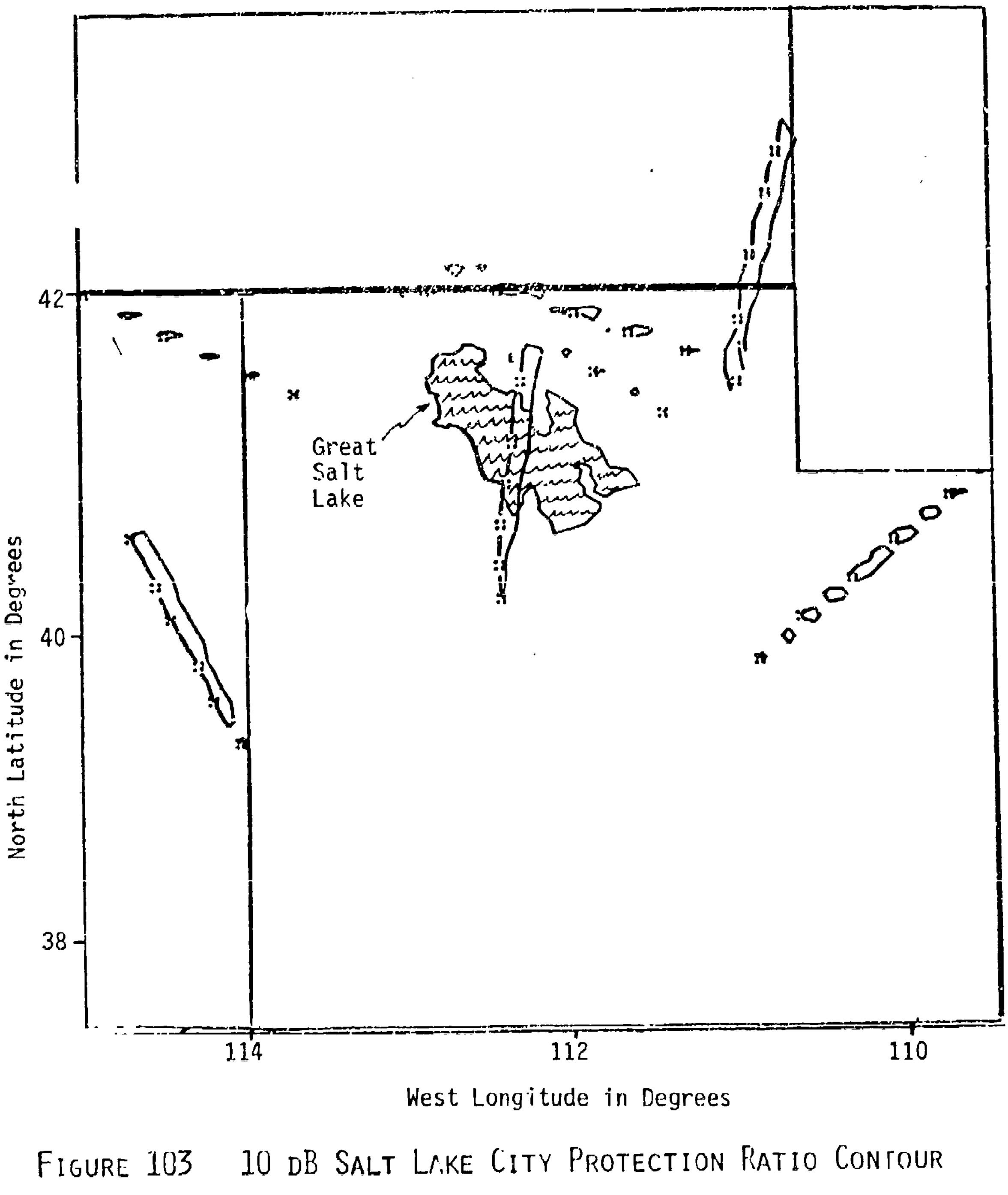


FIGURE 103 10 dB SALT LAKE CITY PROTECTION RATIO CONTOUR

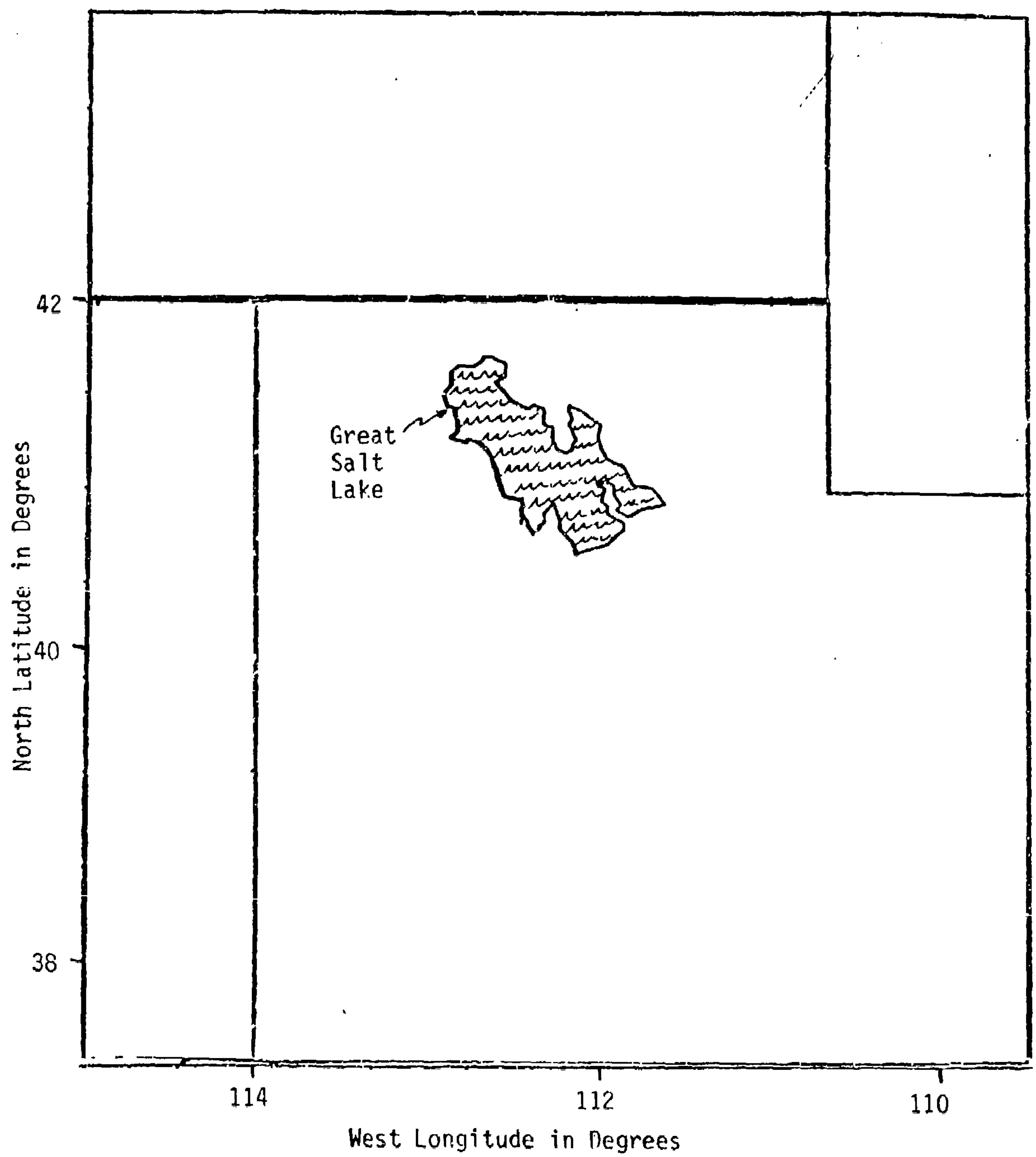


FIGURE 104 5 dB SALT LAKE CITY PROTECTION RATIO CONTOUR

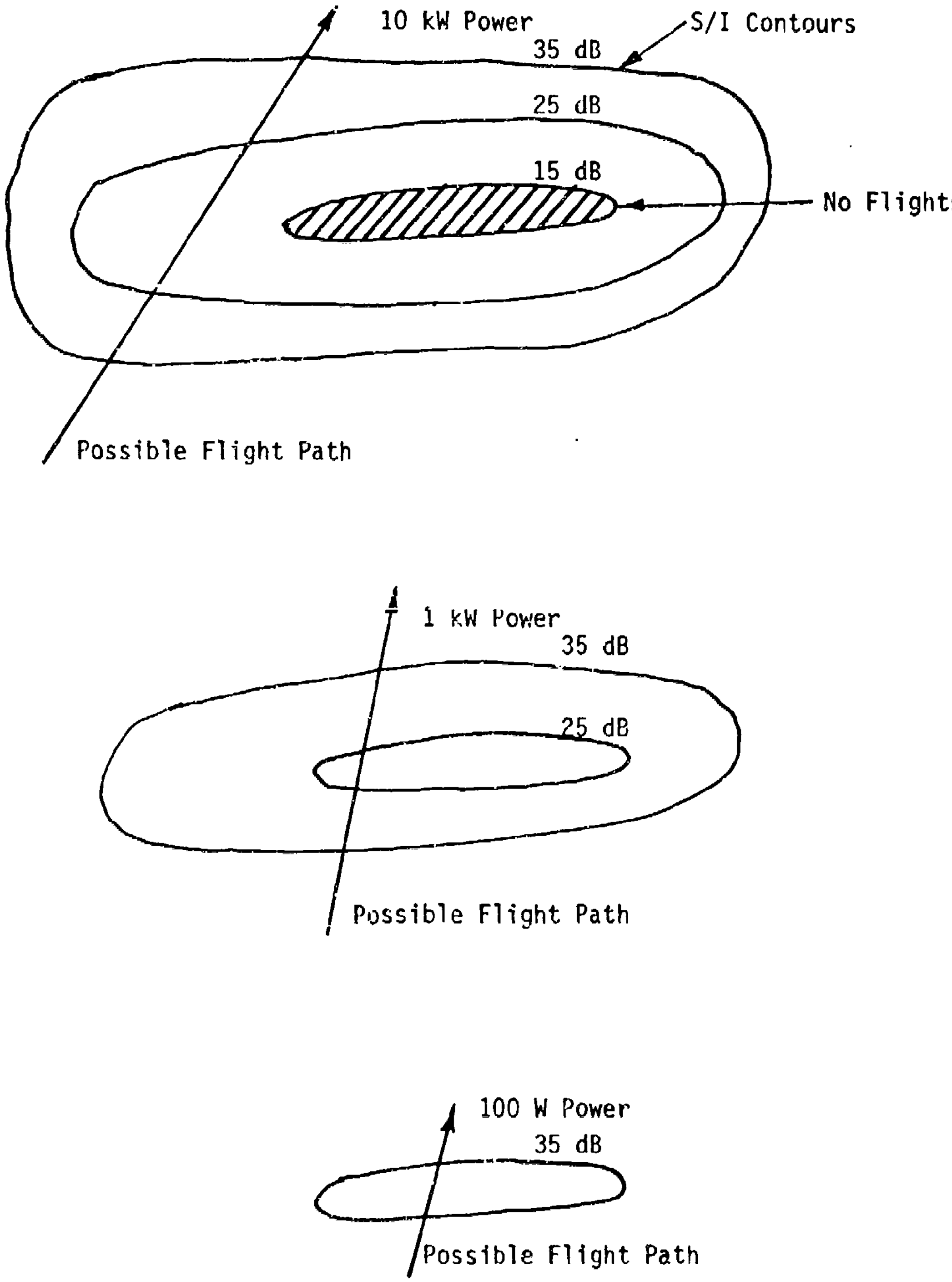


FIGURE 105 TYPICAL S/I CONTOURS

OPERATIONAL CONSIDERATIONS

A number of points should be discussed regarding the relationship between the FAA microwave systems and the SHF SATCOM system. The RML-4 systems provide communication channels between remote radar sites and the enroute control centers (ARTCC). Currently four 15 MHz channels go from the remote radar to the ARTCC and two in the reverse direction. The channels from the radar support both the broadband (non automated) and the narrowband (automated) Air Traffic Control (ATC) configurations.

Most ARTCC's currently operate in the narrowband or automated configuration for approximately 16 hours per day. During the remaining non-peak time the conventional broadband configuration is activated to allow for narrowband system software and hardware maintenance. FAA is currently working on methods that will allow full 24-hour per day operation in the narrowband mode which would keep broadband system exclusively for backup. The backup role for the broadband system may be limited since FAA is currently developing a digital backup capability (Direct Access Radar Channel - DARC) that uses the narrowband data as input. With the installation, checkout, commissioning, and suitable trial period for DARC, it would appear that a need for any broadband capabilities would cease to exist. When this occurs the RF channel needs would be reduced from six to four, i.e., a primary and a spare channel in each direction. If this condition evolved and only the top four channels of the existing frequency plans were used, this would place all channels except one below 7.9 GHz. This of course assumes that Channels 1 and 2 would be in the forward direction. Of the ten frequency plans shown in Table 12, only six would have Channels 3 and 4 above 7.9 GHz. If it is assumed that Channel 3 is primary and 4 is backup then the maximum frequency for any prime channel in the reverse

direction would be 8.025 GHz. The maximum frequency for Channel 4 (the backup channel) would be 8.145 GHz. Under this set of conditions considerable non-overlapping spectrum would exist, hence precluding possible interference. This is an area that the FAA and the USAF should remain cognizant of as their respective systems evolve.

The interference probabilities discussed in this section have been developed considering individual hop outages. Since the overall system's performance is governed by a link's performance, the effect of interference on the link should also be considered. Since the link noise per hop is additive, the overall link noise increases in proportion to the number of hops. For the worst case situation in which the microwave main beams are aligned in a straight line, the interference is coupled into the link in approximately a continuous manner from every other hop in sequence. For this worst case situation, the system noise increases while the interference remains approximately constant. Therefore, the "nature caused" outage time increases and a larger outage time could be specified for the increased outage due to interference. In addition, microwave links are not typically designed to run in a straight line so that the worst case interference coupling situation should never occur. Deriving interference probabilities from individual hop outage times is, therefore, a worst case situation.

CONCLUSIONS

Based on the overall investigation of potential interactions between the airborne command post and FAA microwave equipments, the following conclusions are presented. The bounding assumptions were previously stated in SECTION II.

1. The detailed test and supporting analytic efforts validated the original predictions of interference to the microwave equipments at high transmitted power levels.

2. The performance degradation to a multichannel FM system from PN interference is approximately the same as that from gaussian noise.

3. There is potential for severe interference to all FAA microwave equipments (RML-4, RML-6) which could effect ATC operations. The actual extent of this potential interference is, however, highly dependent on the frequencies selected, power transmitted, flight paths flown, satellites used for relay of communications traffic, and fading conditions on the microwave links.

4. Interference to the broadband terminal and enroute configurations could be in the form of extensive strobing on the display and possible loss of display synchronization. During the PN high power 10 kW flight tests, display strobing was experienced for approximately 90 seconds which is a lower bound number, i.e., the aircraft was flown perpendicular to the main beam which represents the shortest dwell time in the beam. For an upper bound number while flying down the main beam, the periodic strobing of the display might extend over 7 or 8 minutes.

5. For narrowband operations (the automated enroute configuration), extensive loss of messages could be experienced during interference to Channel 3. During the 10 kW tests, data rates were reduced to zero for approximately one minute.

6. Under conditions when the microwave links are not fading, interference can only occur for specific physical configurations, i.e., both the microwave antenna and the airborne SHF SATCOM antenna must be pointed in the general direction of one another (i.e., within approximately 60°).

7. Potential interference could exist for any physical orientation of the aircraft relative to the microwave receiver during periods of microwave link multipath fade.

8. Severe interference to the microwave channels will occur when the aircraft transmits 10 kW. For 10 kW operation, care must be taken to restrict flights from some areas and severely limit flight time within other regions. For 1 kW operation, some flight time limitations are required in specific but limited areas. If 100 watt operation is satisfactory, no flight time limitations are required.

9. The enroute automated system can automatically mosaic up to three levels of radar data to assure reliable coverage in areas where overlapping coverage exists. It appears that where multiple coverage exists, this feature would tend to negate the effects of losing one Channel 3 input because of interference. However, multiple coverage does not exist in enough areas in the CONUS to have this technique become a general solution to the problem.

10. Because of DSCS-II satellite band assignments, it appears that the aircraft must utilize frequencies that lie within the following two bands, 8.125 - 8.175 GHz and 8.215 - 8.400 GHz. Two planned frequencies have been identified (8.150 GHz and 8.240 GHz) which place the aircraft signals in conflict only with five Channel 5 and two Channel 4 RML-4 frequency families. Channel 4 is a spare channel. Channel 5 carries information from the control center (ARTCC) to the radar site, i.e., Backup Emergency Communication (BUEC) voice/data channels, remote switching tones, and some link performance sensing signals.

11. A reversal of RML-4 Channels 5 and 6 (assign 6 active role and use 5 as the spare) would place the aircraft frequencies in potential conflict with the spare and not the active channel.

12. Based on known RML-6 frequency families and the representative aircraft frequencies, it appears that no interaction between the systems should exist.

13. The ATTIC program was used to identify S/I regions associated with two aircraft uplink frequencies, 8.150 and 8.240 GHz. Restricted zones and limited flight time areas associated with 10 kW aircraft operations as well as limited flight time areas for 1 kW and 100 watt options were identified. Considering the CONUS in relationship to the calculated S/I contours, there appears to be considerable airspace and flight path options available that would not create conflicts with FAA operations.

14. Depending on the frequencies selected, the restricted zones and limited flight time areas would be placed in different areas of the country but would, in general, be of the same order of magnitude. The zones for a specific frequency set will, however, change depending on what satellite is being used, i.e., 135°W satellite use creates a somewhat different set of contours than the 13°W satellite.

15. For those links that employ passive reflectors both reflector main beam and parabola main beam interference areas need to be considered.

16. It appears that if specific attention is given to those points identified as being significant (selection of flight paths, frequencies, power budgets, and satellites), then compatible operations can be achieved.

RECOMMENDATIONS

The following recommendations are presented based on a review of conclusions regarding potential interactions between the airborne command post and FAA microwave systems.

1. It is essential that the organization developing or operating the airborne SHF SATCOM system establish an initial and a continuing coordinated flight planning and frequency assignment process for the command post aircraft to take into account any changes in the microwave frequency usage and aircraft frequency requirements. Effective coordination is likely to be a difficult management process.

2. If the high power 10 kW option is required for test, evaluation or operation, extreme care should be take to: (a) assure that restricted interference zones are avoided; and, (b) that flight time limitations in other specified areas are maintained.

3. Every effort should be made to assure that follow-on satellites (DSCS-III) are designed to allow high power operations in the exclusive satellite bands. Concurrently, efforts should be initiated to develop a timetable with FAA such that their limited use of the exclusive bands for microwave communications can be phased out on a schedule that complements the DSCS-III phase-in dates.

4. If the command post can limit the transmitted power to 1 kW, this would allow overflights of all FAA systems if flight time limitations (approximately 13 minutes per day for the 50% outage time criteria) are maintained. Every effort should be made to plan aircraft operations and associated power budgets within these general guidelines.

5. If the command post must operate with the DSCS-II satellites within the general bounds typified by the planned frequencies (8.150 GHz and 8.240 GHz), then the FAA should be encouraged to reverse their RML-4 Channels 5 and 6, i.e., 6 would be active and 5 the spare. This administrative action would eliminate the possibility of interference to all FAA RML-4 systems for all aircraft power options except during periods of Channel 6 failure at which time Channel 5 would be active.

SECTION VIII

JET PROPULSION LABORATORY GOLDSTONE MEASUREMENTS AND ANALYSIS

INTRODUCTION

The Deep Space Network (DSN) established by the NASA Office of Data Tracking and Acquisition is under the system management and technical direction of the Jet Propulsion Laboratory (JPL). It is designed to maintain two-way communication with NASA unmanned spacecraft traveling to the farthest planets of our solar system. Space platforms such as the Mariner, Helios, Viking and Pioneer series send data to the stations of DSN from interplanetary distances. The MARS DSS-14 Station at Goldstone, California has a deep space link which operates at X-band frequency (8.4 to 8.5 GHz). This frequency band is adjacent to the uplink frequency band proposed for use by the airborne SHF SATCOM terminal aboard the E-4. Since it is planned that the E-4 can operate anywhere in CONUS, there is the potential for interference to the Goldstone DSN-14 X-band downlink channels from the airborne SHF SATCOM terminal emissions. There is also a potential problem to susceptible airborne electronics when operating in the Goldstone main beam due to the high power flux density from the interplanetary radars. Goldstone MARS DSS-14 operates an S-band (2390 to ± 5 MHz) planetary radar with a 400 kW peak power capability. In the near future a 400 kW X-band (8495 ± 5 MHz) planetary radar will also be operated at the Goldstone site. For both of these reasons it is advisable to avoid flying through the MARS antenna main beam. The characteristics for the Goldstone MARS DSS-14 are listed in Table 22.

TABLE 22

GOLDSTONE MARS STATION (DSS-14) CHARACTERISTICS

RECEIVER (X-band downlink):	
Noise Temperature	25°K
Antenna Gain	71.5 ±0.6 dBi
Antenna 3 dB beamwidth	0.04°
Frequency	8.4-8.5 GHz
Bandwidth of Maser (3 dB)	69 MHz
PLANETARY RADAR (X-band CW uplink):	
Frequency	2.29-2.3 GHz
	8.4-8.5 GHz (future)
	8495 ±5 MHz
Power	200-400 kW
TRACKING COVERAGE:	
Elevation	6° minimum
Typical Azimuths	100° to 130°
	230° to 260°
COORDINATES:	35°25'33.34"N
	116°53'19.15"W
Station Elevation	1031.8 meters

A quiet area with a minimum of man-made radio interference is very important for the successful reception of data from interplanetary spacecraft. Goldstone mission support requires two or three daily tracking passes of eight to ten hours duration. The Mariner and Pioneer series missions are planned through 1981. In addition, the planetary radars may operate at planetary conjunctions which vary from every three months for Mercury and to every 27 months for Mars. Some radio astronomy scientific investigations are also performed at Goldstone.

The Goldstone tracking missions are usually along or near the ecliptic plane. The spacecraft for deep space missions appear in the east and set in the west in the same manner as celestial objects. Therefore, the north and south excursions of the antenna are usually limited at Goldstone within a tracking volume between plus thirty-seven and minus thirty degrees declination. Goldstone antenna tracking envelopes are shown in Figure 106.

GOLDSTONE X-BAND RECEIVER

The X-band receivers for deep space communications are designed to receive information with low signal-to-noise ratios. The high sensitivity DSN receivers are characterized by low noise temperatures and high stability for both wide and narrowband reception. The low noise temperature is achieved with a cooled traveling wave tube maser amplifier and a carefully designed antenna system. Narrow bandwidth receiver channels use phase lock techniques to track carrier in a 12 Hz loop noise bandwidth. The present maser amplifier has a 61 MHz bandwidth (1 dB points) which receives 8.40 to 8.44 GHz. Although the entire 100 MHz band allocation from 8.4 to 8.5 GHz has future data channel assignments for the DSN, there are only four assignments presently in use (8402.7, 8409, 8415 and 8420 MHz).

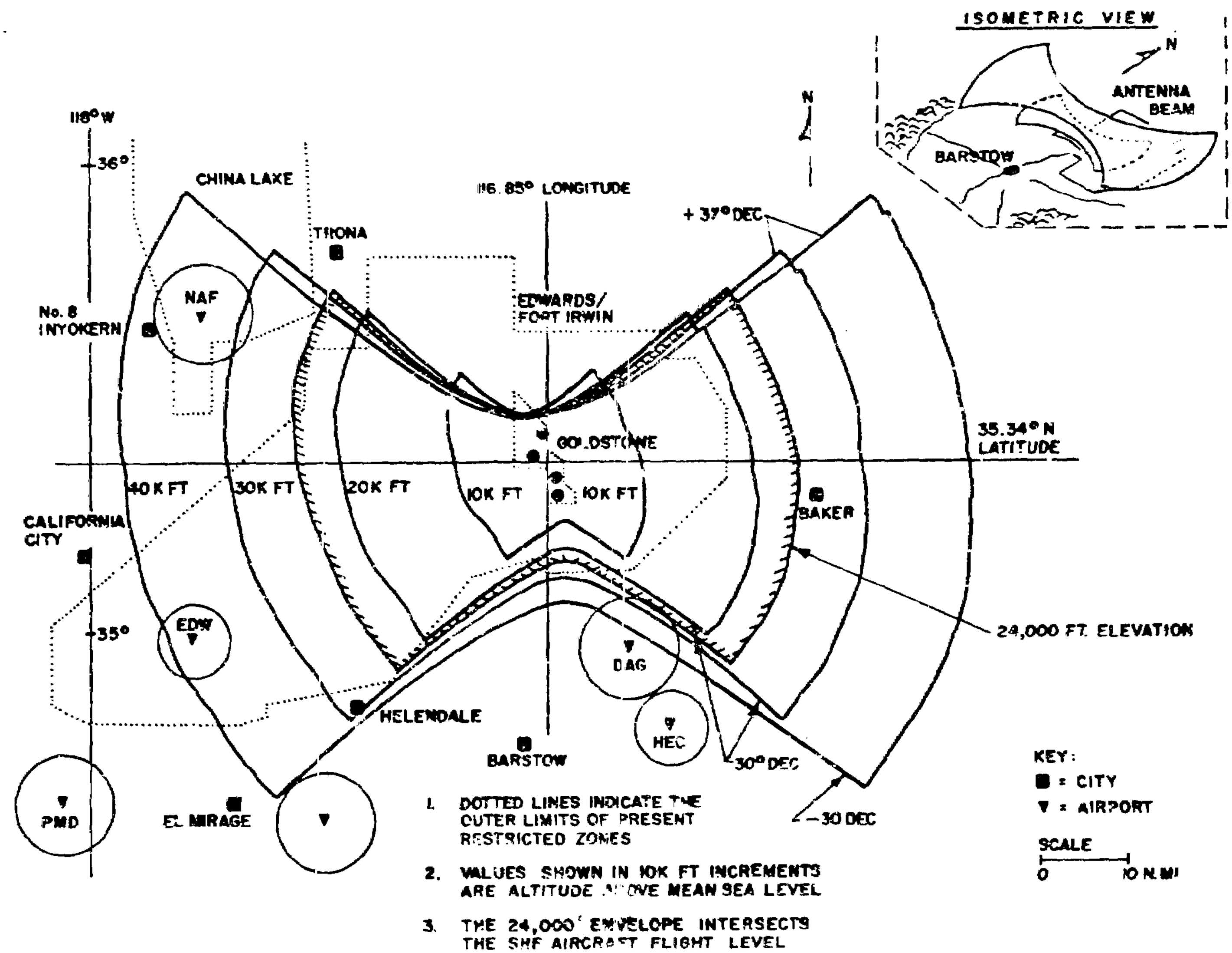


FIGURE 106 GOLDSTONE DSN-14 ANTENNA POINTING ENVELOPES (6° MINIMUM ELEVATION)

DEGRADATION CRITERIA FOR GOLDSTONE MARS X-BAND

The frequency allocations for Goldstone DSN X-band and the airborne SHF SATCOM terminal are not overlapping. Therefore, no co-channel interference situations between these two systems have been identified. The adjacent signal emissions from the airborne SHF SATCOM terminal on the E-4, however, present sources of potential interference to the MARS X-band system.

Adjacent out-of-band signal interference (that has significant energy within the Maser RF noise bandwidth such as uplink klystron amplifier (channel 6 of the airborne SHF SATCOM transmitter) can degrade the DSN maser amplifier and drive it into saturation. A signal level of -90 dBm is necessary to drive the X-band traveling wave tube maser amplifier into saturation. Reference 29 states that degradation of the maser performance, however, can be caused by undesired signals at a much lower level than -90 dBm.

In addition, any wideband signal or noise spectrum which overlaps the maser bandwidth can degrade the receiver signal-to-noise (S/N) ratio. The degraded S/N ratio will affect the phase lock loop and data channel performance. The reason for this low level of interference causing degradation is that the DSN receivers obtain data from signals that are typically only 2 to 5 dB above the receiver system noise temperature. The thermal noise (KTB) for this X-band maser was calculated to be -106.2 dBm, using an effective system noise temperature of 25° Kelvin and a 3 dB noise bandwidth of 69 MHz. Interference power levels of -106.2 dBm within the RF bandwidth are lower than the -90 dBm X-band maser gain suppression threshold. Therefore, the maser gain will not be affected by this signal.

A third degradation mode for the X-band receiver can be caused by wideband noise from frequency adjacent transmitters. This interference situation exists for the airborne SHF SATCOM terminal which has transmitter emission noise spaced several hundred megahertz from the carrier frequency. With a system noise temperature of 25°K, the noise spectral density for the X-band receiver is -184.6 dBm/Hz. Reference 29 stated that the interference criterion for wideband noise is that it is at least 5 dB below the receiver noise spectral density level. This level is predicted not to degrade the receiver performance by more than 1 dB (an increase in system noise temperature of 5.7°). For this X-band receiver, the maximum permissible wideband noise interference spectral density is, therefore, considered to be -190 dBm/Hz. This interference threshold will be referred to later in this report as the "JPL criteria" for system noise temperature.

JPL MARS TEST CONFIGURATION

To evaluate the potential interference a series of ground and flight test measurements were made. Prior to the test the measuring equipment was set up and calibrated at the JPL Goldstone facility to evaluate the amount of energy coupled into the JPL 210 foot antenna X-band receiver system from the SHF SATCOM test aircraft. During the test an R&D maser amplifier was used with a 3 dB bandwidth of 20 MHz. This has now been replaced by the operational wideband maser which has a 3 dB bandwidth of 69 MHz.

In preparation for this SHF airborne flight test the R&D X band maser amplifier with its 20 MHz bandwidth was connected to the 210 foot Goldstone antenna system. See Figure 107 for the ground test equipment set up. The effect of interference on the IF broadband noise in a 1 MHz bandwidth was monitored with a square law detector for any increase in the ambient

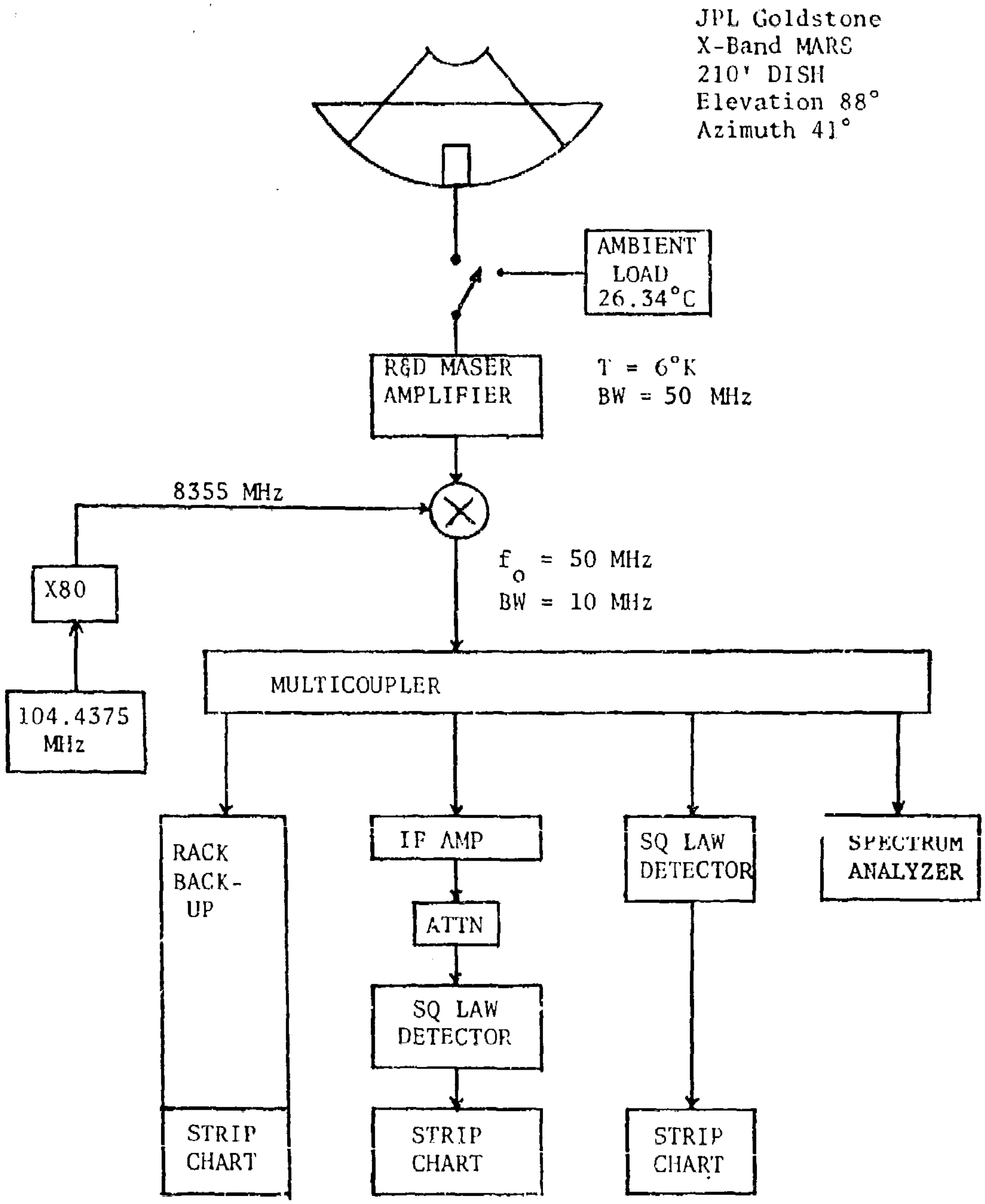


FIGURE 107 TEST SETUP FOR JPL GOLDSTONE X-BAND FLIGHT TEST

noise level. Off-tuned response or susceptibility of the wideband maser was approximated for this test by tuning the R&D maser amplifier at 8405 MHz.

The amount of interference received by the JPL X-band system was evaluated by observing any increase in the X-band system noise temperature. The R&D maser amplifier did not have the telemetry capability so no bit error rate measurements could be obtained during this flight test.

The JPL technical personnel calibrated the X-band system noise temperature at 22.2°K while the antenna was pointed near its zenith point (elevation 88°, azimuth 41°). During the flight test strip chart recorders were used to continuously record the X-band system noise temperature over the range from 22.2°K to 100°K.

FLIGHT TEST AT THE JPL MARS FACILITY

A flight test to evaluate the effects of interference from the airborne SHF SATCOM terminal emissions on the MARS 210 foot antenna and X-band system were performed on 28 May 1975. It has been predicted that operation of the airborne SHF SATCOM terminal within the MARS 210 foot antenna main beam or sidelobe would cause interference at the receiver input of the MARS X-band system. Therefore, the flight tests were planned to determine the frequency and distance separation situations which would protect the MARS X-band system from the SHF terminal emissions for a given set of operational conditions. This involved flying in an area near the MARS 210 foot antenna main beam. During most of the flight tests, the SHF SATCOM antenna was in the operational satellite mode orientation which would be pointed at 42° elevation and at an azimuth toward the position of the western DSCS Phase II satellite. The aircraft operated at an altitude of 26,000 feet msl.

The MARS 210 foot antenna was pointed near its zenith at 88° elevation and 41° azimuth for all of the flight tests. The MARS X-band system noise temperature was continuously monitored during the flight test for any increase above the 22.2°K ambient noise temperature. For this first "worst case" overflight, the SHF terminal transmitted PN on the klystron amplifier Channel 6 (8360 MHz center frequency) with a 40 Mbps data rate. The transmit power level was switched between 100 watts and 10 kW at one minute intervals. As the test aircraft flew northward from a point 90 nm south of the MARS antenna, no increase in MARS X-band system noise temperature was observed until the aircraft was 74 nm south of the MARS antenna. At that distance, the noise temperature increased for a four second period by 0.2° to a level of 22.4°K. The interference density level required to raise the MARS X-band -185 dBm/Hz noise floor by 0.2° is -205.4 dBm/Hz. Sampled data points from the strip chart of this overflight are included in Table 23. At the closest approach to the MARS main beam, the MARS X-band system noise temperature was observed to go off the strip chart indicating a level in excess of 100°K (Reference GMT 17:08). Note in Table 23 that the JPL interference criteria of +1 dB of noise density increase (+5.7°C above 22.2°K) was exceeded for a 12 second period. A 2 nm offset ground distance from the MARS antenna was noted as the aircraft flew by the MARS antenna. This 2 nm offset calculates for a MARS antenna off boresite angle of about 28° which results in a reduced coupling factor from the MARS antenna. The geometry for this offset situation represents an aircraft antenna off-axis angle of 104°. The calculated mutual antenna coupling factor for the 2 nm offset geometry was -29 dB. Thismmutual antenna coupling loss may be accounted for by a combination of aircraft

TABLE 23

MARS X-BAND SYSTEM NOISE TEMPERATURE DURING FIRST OVERFLIGHT

GMT REFERENCE TIME	SEPARATION TO NORTH OR SOUTH FROM MARS IN NM	RECORDED NOISE TEMPERATURE ΔTe IN °C	Te IN °K	RECEIVED INTERFERENCE DENSITY IN dBm/Hz	DURATION OF INTERFERENCE IN SECONDS
1654	88S	0	22.2	-	
1656	74S	0.2	22.4	-205.4	4
1650	62S	1.35	23.6	-197.2	3
1700	50S	1.48	23.7	-196.7	13
1702	38S	1.0	23.2	-198.5	7
1704	25S	1.56	23.8	-196.4	
1706	13S	2.3	24.5	-194.8	1
		5.7	27.9	-191.0	exceeded for 12 seconds
1708	1S	78.0	100.0	-179.5	exceeded for 4.8 seconds
1710	11N	0	22.2	-	
1712	23N	0	22.2	-	
1714	35N	0	22.2	-	
1716	47N	0.8	23.0	199.4	2
1718	58N	0.2	22.4	-205.4	
1720	70N	0.4	22.6	-202.4	
1722	82N	0	22.2	-	

NOTES: Aircraft at 26,000 feet, antenna had a simulated satellite orientation of +42° elevation and pointing towards Goldstone.

Modulation PN, Channel 6, Power 10 kW

Offset was 2 nm from MARS main beam

100 watt intervals not included in table since noise temperature indicated ambient level.

shielding at 2 nm for -22 dB (see Figure A-9) and the CCIR antenna envelope gain prediction at 28° off axis of -6 dBi for the MARS 210 foot antenna. Two more overflights were made with Channel 6 at 10 kW with PN modulation. The interference levels coupled into the MARS X-band were similar to those listed in Table 23. The greatest distance separation for an observable increase in X-band noise temperature was during an outbound pass at 132 nm when a 0.2° temperature increase was recorded.

To further bracket the potential interference the final overhead pass at 19:14 GMT had the transmit power levels switching between 1 kW and 10 kW. Channel 6 and the PN modulation were selected. The 1 kW power level was observed to cause a small increase in X-band noise temperature which did not exceed the JPL criteria of +5.7°C except for one spike of +11° amplitude. This occurred about 6 nm from the MARS antenna. As the aircraft passed overhead the MARS antenna main beam, the JPL threshold criteria was exceeded for 24 seconds when 10 kW PN modulation, Channel 6 was transmitted. The peak envelope of the interference was unknown since it exceeded the 100°K calibrated level of the strip chart for about 9.6 seconds. A spectrum analyzer display of the receiver bandwidth for this peak envelope interference provided an estimate of about 12-15 dB above the ambient level.

One overflight which did not produce any noticeable increase in the monitored X-band noise temperature occurred when Channel 1 transmitted an alternate 10 kW and 100 watt power with PN modulation. Channel 1 center frequency was 7940 MHz.

The remaining portion of the tests consisted of orbit type of flight profiles. The orbit center was located approximately 36 nm south of the MARS 210 foot antenna. See Figure 108 for a diagram of the orbit profile

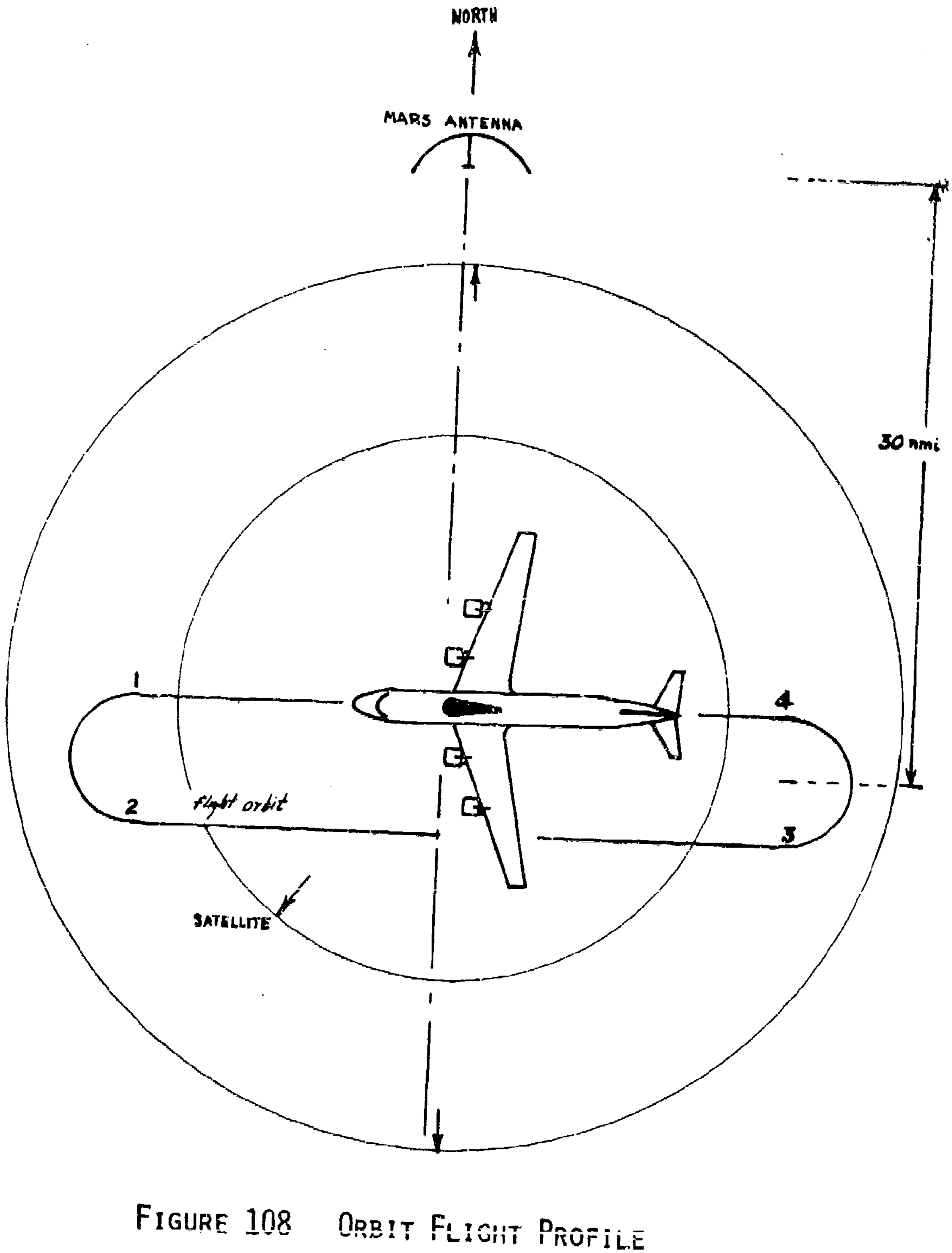


FIGURE 108 ORBIT FLIGHT PROFILE

and its relative location to the MARS 210 foot antenna. During an orbit with simulated satellite antenna orientation, Channel 4 (8225 MHz) with PN modulation and 10 kW of power did not cause any noticeable increase in the X-band noise temperature. To increase signal coupling, the airborne SHF SATCOM antenna elevation was decreased from 42° to 10° elevation. With this increased signal coupling, the Channel 4 still did not cause any observable increase in the X-band system noise temperature. Channel 5 (8275 MHz, PN modulation, 10 kW) was also evaluated with increased coupling at 10° elevation while performing an orbit. No increase in the X-band noise level was observed.

During an orbit, Channel 6 (8360 MHz) was selected with PN modulation and 100 watts transmit power. With the airborne SHF SATCOM antenna in the typical or the simulated satellite orientation towards the MARS station, there was not any observable increase in MARS X-band noise level.

When Channel 6 operated with 10 kW and PN modulation, interference was observed at the MARS X-band system. During several of the orbit profile passes, the JPL noise temperature criteria was exceeded while the MARS antenna was pointing near its zenith and the airborne SHF SATCOM terminal was 30 to 41 nm south of the MARS antenna. The aircraft antenna was either at a simulated satellite orientation angle or at 10° elevation and the aircraft was at 26,000 feet msl. A summary of selected orbits is presented in Table 24. The GMT times are for referenced events 12, 13, 14, 23 and 24 on the flight test log for 28 May 1975.

While still transmitting on Channel 6 at 10 kW, the modulation was changed to a frequency hopping mode for one orbit. The frequency hopping (FH) did not cause any noticeable increase in the monitored X-band noise

TABLE 24

SHF SATCOM ORBIT TEST SUMMARY AT DSS-14 ON 28 MAY 1975

GMT	ORBIT LEG	TX PWR IN kW	MOD TYPE	SHF SATCOM ANTENNA ELEVATION	RECORDED NOISE TEMPERATURE °K	CALCULATED I, dBm/Hz	I/N RATIO in dB	PERIOD JPL NOISE CRITERIA WAS EXCEEDED
18:47:51	East turn	10	PN	42°	69	-181.8	+3.2	12 seconds
18:48:00	4 to 1	10	PN	42°	>100	-179.8	+5.2	110
18:50:18	West turn	10	PN	42°	70	-181.7	+3.2	30
18:52:00	2 to 3	8	PN	10°	>100	-179.8	+5.2	18
18:53:44	East turn	8	PN	10°	>100	-179.8	+5.2	30
18:55:42	4 to 1	8	PN	10°	96	-179.8	+5.2	96
18:58:00	West turn	8	PN	10°	72	-181.5	+3.5	24
18:59:22	2 to 3	8	FH	10°	22.2	------	---	0
19:25:10	4 to 1	1	None	-7°	23	-199.4	-14.4	0
19:29:40	2 to 3	1	PN	42°	22.2	------	---	0
19:30:45	East turn	1	PN	10°	27.9	-191	-6	0.5
19:32:45	4 to 1	1	PN	10°	24.2	-195	-10	0
19:34:45	West turn	1	PN	10°	33.8	-187.8	-2.8	2.4

Aircraft at 26,000 msl, orbit at 30-40 nm south of MARS transmit frequency 8360 MHz with indicated modulation MARS antenna at 88° elevation, 41° azimuth, R&D maser (20 MHz)-8405 MHz

temperature. The FH signal however, was observed on the spectrum analyzer at the out-of-band lower edge of the MARS receiver response. This indicates that because of FH modulations lower sideband content, which did not spill into the MARS bandpass, the 10 kW Channel 6 FH signal did not exceed the out-of-band power density criteria for degradation.

An evaluation of interference from Channel 6 with CW modulation (8360 MHz) simulating a narrowband FM (10 kHz p-p deviation) at 10 kW was performed. No increase in the MARS X-band noise level was observed. The CW signal was observable on the spectrum analyzer 45 MHz below the MARS center frequency of 8405 MHz.

Evaluation of the airborne SHF SATCOM transmitter thermal noise as an interference source was performed by setting Channel 6 (8360 MHz) at 10 kW output power and then inhibiting the IF drive input signal. This created the highest transmitter noise floor output. There was no observable increase in the MARS X-band noise level during an orbit with the aircraft antenna in a simulated satellite orientation. When the aircraft antenna was depressed to a -7° elevation directly towards the [illegible] to create a situation of maximum coupling (an increase o[illegible] dBi) there was observed a small increase of X-band noise te[illegible] or about 0.8°C. This 0.8°C increase represents an interference noise level of -199.4 dBm/Hz from the aircraft at 38 nm distance separation from the MARS antenna.

Channel 5 (8275 MHz) with PN modulation at 10 k[illegible] ower did not cause any noticeable increase in the X-ban[illegible]se le[illegible] while the aircraft made an orbit.

There is one more mutual antenna coupling situation that was not evaluated during the flight test. It involves the MARS antenna pointing low in elevation angle in the direction of the orbiting aircraft. This situation will be discussed in the following section of this report.

DISCUSSION OF RESULTS

Considering the coupling geometry for the JPL MARS 210 foot antenna during the flight test there are several observations that can be made for the airborne SHF SATCOM terminal when its antenna is oriented toward the location of the western DSCS Phase II satellite position. Klystron amplifier Channels 5 through 1 can be operated adjacent to the MARS 210 foot antenna 6° elevation tracking volume (see Figure 106) without causing interference levels to MARS X-band system which exceed the JPL criteria (+1 dB noise level increase). Klystron amplifier Channel 6 (8360 MHz) can be operated at 10 kW in an area adjacent to the MARS 210 foot tracking envelope without exceeding the JPL criteria for three conditions: (1) narrowband FM, (2) frequency hopping (FH) mode, and (3) without RF drive (Klystron thermal noise).

Channel 6 with PN modulation can operate at 100 watts transmit power without exceeding the JPL criteria in areas adjacent to the MARS 6° tracking envelope. All of the above situations assume that the airborne SHF SATCOM antenna is satellite oriented, at 42° elevation angle when operating near the MARS facility.

For Channel 6 with PN modulation, there are additional restrictions for high power operation (1 kW and 10 kW) when in the areas adjacent to the 5° elevation MARS tracking envelope. When the airborne SHF SATCOM terminal operates in an area to the east of the MARS X-band facility, there will

be the possibility of increased coupling over the test orbit condition and the overflight situation if the MARS antenna is also pointing low in elevation and toward the east. Compared to the situation of a low elevation angle for the MARS antenna, the orbit test flights had increased isolation due to the MARS antenna far out sidelobe coupling in the direction of the aircraft. The overflights had more isolation due to aircraft shielding (about -22 dBi coupling loss when the aircraft was overhead). Note that during portions of both the orbit flights and the overflights that the JPL criteria was exceeded when Channel 6 transmitted with PN modulation at 10 kW.

An estimate of the received interference signal level by the MARS X-band system when its antenna is pointing low in elevation angle over an orbiting aircraft which is 36 nm away from the MARS antenna can be extrapolated from the orbit test flights, which had the MARS antenna at zenith. For this situation, the MARS antenna is assumed to be low in elevation and pointing with only a few degrees off-axis from the direction of the aircraft. The MARS off-axis antenna envelope coupling in the direction of the airborne SHF SATCOM antenna is expected to increase from -6 dBi (80° off axis) to +4 dBi for 3° to 4° off-axis angle. The strip chart recording indicates that when the aircraft flew in front of the MARS antenna at distances of 39 to 41 nm to the south, transmitting on Channel 6 with PN modulation either 8 and 10 kW, that the MARS X-band system noise temperature increased from 22.2°K to over 100°K for two passes, see Table 24. A 100°K increase corresponds to 5 db increase over the ambient level of -185 dBm/Hz or a received interference density level of -180 dBm/Hz. This interference

level is 10 dB above the JPL criteria of -190 dBm/Hz. For the MARS low elevation angle situation, the X-band noise level in the direction of the aircraft is expected to increase by 16 dB due to the decreased MARS antenna off-axis coupling. The expected received interference level could be -164 dBm/Hz or 26 dB above the JPL criteria.

Interference protection to the JPL MARS system in this low elevation angle situation can be provided by distance separation or frequency separation. Reference 28 presents a method for predicting the required distance or frequency separation between the MARS station and the airborne SHF SATCOM terminal. Table 25 contains examples of separation distances for off-axis antenna coupling situations.

The separation distances listed in Table 25 assume an airborne SHF SATCOM terminal altitude of 24,000 feet msl. If a higher operational altitude is required the separation distances may have to be increased.

As previously mentioned any main beam coupling situation to MARS from the airborne SHF SATCOM terminal has a very high probability of resulting in interference to the MARS X-band system. The actual main beam encounter by an aircraft flying through the MARS 210 foot tracking volume (most of the 6° elevation volume for 24,000 foot msl altitude is located within restricted airspace) is very unlikely. A model for predicting main beam encounter for an aircraft randomly flying through the MARS tracking volume is presented in Reference 29. The probability of a single overflight penetrating the MARS antenna main beam is less than 8.7×10^{-5} or one in 11,489 overflights. At least academically it can be argued that with sufficient frequency separation (a 66 MHz separation can protect MARS from the airborne SHF SATCOM terminal emissions as long as MARS main beam

TABLE 25

SEPARATION DISTANCES TO PROTECT GOLDSTONE X-BAND FROM SHF SATCOM EMISSIONS

SHF SATCOM			SEPARATION FROM GOLDSTONE	
Channel	Power	Modulation	Distance in nm	Direction
6	10 kW	PN	124	East-radius
			90	NE, SE
			35	NW, SW
			46	West-radius
6	10 kW	Narrowband	36	East & West radius
		FM & FH	28	N and S
6	1 kW	PN, FH	60	East-radius
		Narrowband	45	NE, SE
		FM	28	NW, SW
			36	West-radius
5-1	10 kW	All types	36	East-radius
			28	N and S
			36	West-radius

coupling does not occur). Only one out of 11,500 overflights are likely to produce interference to the MARS X-band system.

CONCLUSIONS

The flight tests have provided information on the distance and frequency separation necessary to protect the MARS X-band system from potential interference from SHF SATCOM terminal emissions. This is based upon the MARS antenna never pointing to within 2° of the SHF SATCOM aircraft. Other assumptions are stated in SECTION II.

1. The MARS antenna main beam encounter can be avoided by the airborne SHF SATCOM terminal at 24,000 feet msl if it maintains a radial separation distance to the east and west of 36 nm from the MARS station and parallel distance separation to the north and south of 28 nm.

2. Klystron amplifier Channels 1 through 5 (7940 to 8275) can operate at 10 kW of power with PN, FH and narrowband FM modulation in areas adjacent to the envelope described in 1.

3. Klystron amplifier Channel 6 (8360 GHz) can operate at 10 kW with two types of modulation, FH and narrowband FM as long as the separation distances in 1 are maintained.

4. Channel 6 with PN modulation can operate at 1 kW in areas adjacent to the envelope bounded by a radius of 60 nm east of MARS, a radius 36 nm west of MARS, and north and south separation distance of 45 nm along the east radius and a north and south separation distance of 28 nm along the west radius.

5. Channel 6 with PN modulation and 10 kW of power requires a separation area bounded by an east radius distance of 124 nm, a west radius of 46 nm, a north and south separation distance of 90 nm along the

east radius and a north and south separation distance of 35 nm along the west radius. Figure 109 is a summary of these areas.

6. As long as the MARS antenna main beam encounter is avoided by the airborne SHF SATCOM terminal and a channel center frequency separation of 66 MHz is maintained, it is predicted that an overflight could occur with the airborne SHF SATCOM terminal operating at 10 kW and interference to the MARS X-band facility will have the probability of occurrence of less than 1 in 8.7×10^{-5}. This is once in 32.3 years at the rate of one overflight per day.

RECOMMENDATIONS

All encounters with the MARS antenna main beam should be avoided by the airborne SHF SATCOM terminal.

The interference protection envelopes shown in Figure 109 should be maintained by the airborne SHF SATCOM terminal.

As the present restricted airspace which protects the MARS station covers most of the protection envelopes area, consideration should be given to using this area as the boundary for 10 kW Channel 6 PN operation. The uncovered area is in use for only 3 to 4 months a year when the ecliptic plane cuts the Barstow area. Also, major airlines with "hot jet exhaust" presently fly across this area with about 25 to 100 flights per day without apparently causing problems. At a cruise airspeed of 400 to 450 kts, a jet aircraft flies quickly across this area.

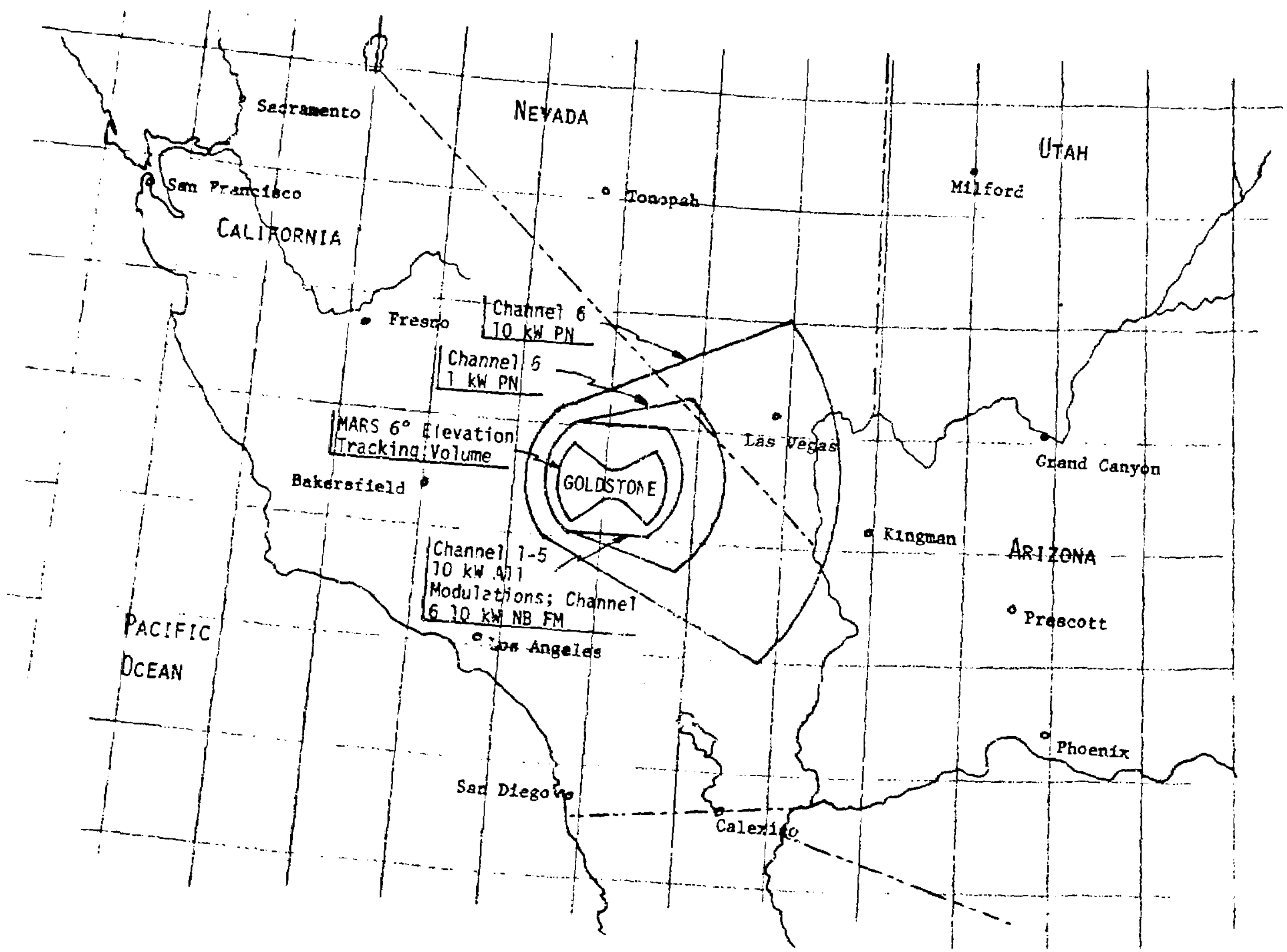


FIGURE 109 PREDICTED INTERFERENCE ENVELOPES FOR GOLDSTENE DSS-14

SECTION IX

EARTH RESOURCES SURVEY OPERATIONAL SYSTEM (ERSOS) ANALYSIS

INTRODUCTION

The Department of the Interior has submitted a plan to IRAC containing the radio communication requirements for the ERSOS program [sometimes referred to as the Earth Exploration Satellite (EES)], originally proposed for implementation in 1978 (Reference SPS-663/1-1.14.10 and DOC 14830/1-4.9.6). The system for ERSOS includes one or more low altitude satellites (which can optically survey the earth's surface every 18 days), numerous data collection earth platforms, a data handling facility for processing data for users, and the satellite command and tracking facilities. The only portion of the ERSOS system which is of concern in this investigation is the downlink from the satellite which has its proposed operational frequencies in the 8.025 - 8.4 GHz band. The ERSOS satellite system is proposed as an operational follow-on to the present NASA experimental Earth Resources Technology Satellites (ERTS or Landsat). ERSOS will be operated by the Department of the Interior/NASA and includes proposed receiving earth stations at Sioux Falls, South Dakota and Fairbanks, Alaska.

The planned deployment for one of the airborne SHF SATCOM terminals is in a peacetime orbit in the north-central CONUS area which includes Sioux Falls, South Dakota. The orbiting aircraft may penetrate the tracking volume surrounding the ERSOS earth station.

The channel frequencies proposed for ERSOS are 8.3025, 8.3525 and 8.3875 GHz. These ERSOS downlink channels are in the 7.9 to 8.4 GHz band to be used by the airborne SHF SATCOM terminal.

ERSOS TECHNICAL CHARACTERISTICS

The ERSOS satellites will transmit three types of information. Two are from imagery sensors, a four band "multispectral scanner system" (MSS), and a "return beam vidicon" (RBV) camera system. The downlink data from these sensors will be transmitted from the satellite on two wideband (25 MHz) channels. The MSS data will use PCM/FM modulation with a 15.06 Mbps data rate. The RBV information will utilize FM/analog modulation with a baseband response requirement of DC to 3.2 MHz. A third downlink channel from the satellite will be used for relaying telemetry information. This telemetry channel will have PCM/PSK/PM modulation with a narrow bandwidth of 5 MHz. The ERSOS earth-station characteristics used in the analysis are listed in Table 26.

The planned orbit for the ERSOS satellite will be sun-synchronous with a 103.3 minute period. The satellite will, therefore, be above the earth's surface by 570 statute miles (970 km). The orbit inclination angle of 99° will shift the apparent position or ground track of successive passes for coverage of the entire globe every 18 days. Information exchange can occur when the satellite is visible to either one of the ground stations. Although the downlink data will be transmitted in 10 minute periods, this does not help much in reducing the overall tracking volume required for data acquisition. Nearly full east/west azimuthal coverage will be needed for data acquisition at some time by the earth stations, due to the apparent shift in the ground tracking path.

INTERFERENCE TO ERSOS EARTH STATIONS

Interference from the airborne SHF SATCOM transmitter to the ERSOS earth-station receiver can occur when the input signal-to-interference

TABLE 26

ERSOS SHF BAND DOWNLINK ANALYSIS CHARACTERISTICS

EARTH STATION PARAMETER	CHANNEL WIDEBAND (RBV + MSS)	NARROWBAND (TLM)
System Noise Temperature at 5° Antenna Elevation	165°K	125°K
Noise Bandwidth	30 MHz	5 MHz (TLM)
Modulation Type	FM Analog (RBV) PCM/FM (MSS)	PCM/PSK/PM (TLM)
Baseband Data Rate	DC-3.2 MHz (RBV) 15.06 Mbps (MSS)	1 to 24 kbps (TLM)
Peak Deviation	5.6 MHz (RBV) 5.6 MHz (MSS)	
Baseband Filter B.W.	3.5 MHz (RBV) 15 MHz (MSS)	
FM Improvement Factor (Processing Gain)	13 dB (RBV) 0 dB (MSS)	
Channel Frequency	8.3025 GHz (RBV) 8.3525 GHz (MSS)	8.3875 GHz (TLM)
Receive Antenna Gain with Right Hand Circular Polarization	55.2 dBi	55.0 dBi
Antenna 3 dB beamwidth (30 foot diameter Cassegrain)	.28°	.28°
ERSOS SATELLITE PARAMETER	**WIDEBAND**	**NARROWBAND**
TX Power	20 watts	0.2 watts
System Loss	2 dB	2 dB
Antenna Gain	4 (dBi)	4 (dBi)
Camera SNR (in IF) (Peak Signal/RMS Noise)	30 dB	
MSS	BER $< 10^{-5}$	
TLM		BER $< 10^{-6}$

$(S/I)_{IN}$ protection ratio is reduced below an acceptable value. The $(S/I)_{IN}$ protection ratio for the ERSOS downlink channels varies as a function of the level of the received desired signal, the type of modulation, and the requirement for quality of data. For example, the RBV camera information has a signal-to-noise $(S/N)_{IN}$ power ratio in the IF channel of 30 dB. The degradation limit was specified as a decrease of 1 dB in this camera $(S/N)_{IN}$ ratio. The downlink microwave transmission must have a $(S/I)_{IN}$ ratio which is adequate to preserve the 29 dB video $(S/N)_{IN}$. Determination of the applicable $(S/I)_{IN}$ ratio includes a calculation of the desired received signal-to-noise $(S/N)_{IN}$ power ratio for the ERSOS receiver and an estimation of the FM improvement factor for each type of channel. The desired received signal $(S/N)_{IN}$ can be calculated with the aid of Equation 3-9 after rearranging terms which is expressed in logarithmic form:

$$(S/N)_{IN} = P_T - L_S + G_T + G_R - L_{FS} - N_S - L_A \quad \text{(dBm)} \qquad (9\text{-}1)$$

where

P_T = satellite transmitter power in dBm

L_S = coupling device loss in the satellite in dB

N_S = receiver noise calculated from KTB

The rest of the terms are defined in SECTION III.

When the satellite is directly over the ERSOS earth station, the downlink $(S/N)_{IN}$ was calculated to be 31.6 dB into the receiver. A theoretical FM improvement factor for the microwave channel with the camera data of 13 dB was calculated. OT investigations indicate that a $(S/I)_{IN}$ ratio of 18 dB is adequate to protect this wideband microwave link.[14] A summary of the S/I ratios which are predicted to protect the downlink ERSOS data channels is listed in Table 27. The downlink channel

with the RBV camera data is the most critical from an interference standpoint. The RBV camera channel will be considered in this analysis.

TABLE 27

MINIT $(S/I)_{IN}$ PROTECTION RATIOS FOR ERSOS DOWNLINK WITH SATELLITE AT ZENITH

	ERSOS Data Channels		
	RBV	MSS	TLM
S/I in dB	18	15	12

When the ERSOS satellite is close the the horizon (5° elevation), the received signals at the earth station have a lower level by 9 to 10 dB than for the zenith situation. For the low elevation tracking angle signals, the MSS and TLM channels S/I ratios listed above are still adequate, but the RBV channel $(S/I)_{IN}$ ratio must be increased to 20 dB.

The undesired received power (I) can be calculated by Equation 9-1.

The airborne SHF SATCOM terminal deployed near Sioux Falls, South Dakota would communicate with the geostationary DSCS Phase II satellite located at 135° west longitude. The look angle to this satellite will be above 25° elevation. This elevation angle is high enough to prevent the main sidelobe (and main beam) from possible energy-coupling to the ERSOS earth-station receive antenna at Sioux Falls. Thus, the median sidelobe gain value of -1 dBi will be used as the airborne SHF SATCOM antenna gain in this analysis.

ERSOS MAIN BEAM COUPLED INTERFERENCE

While the probability that an aircraft would actually encounter the ERSOS antenna main beam is very small, the worse case coupling with the ERSOS main beam is considered here to provide an upper bound on the problem.

The ERSOS receive antenna gain has a main beam value of 55.2 dBi. The antenna configuration is cassegrain with a 30 foot diameter parabolic reflector. The ratio of aperture-to-wavelength for this antenna is great enough to apply the CCIR antenna model for large antennas for computing the antenna sidelobe envelope.[30] The receive antenna gain, represents the main beam gain reduced by the off-axis factor. The victim antenna is considered to be pointing in the general direction of the airborne SHF SATCOM terminal.

The Off Frequency Rejection (OFR) curve for the airborne SHF SATCOM terminal emission and the ERSOS wideband receiver channel was calculated. This curve was obtained from the emission spectrum in Reference 3 and calculated with the ECAC OFRCAL program. The off frequency rejection curve is shown in Figure 110.

The propagation loss was computed for the situation at the ERSOS earth station. The airborne SHF SATCOM terminal was assumed to be at 24,000 feet altitude. The propagation loss curve is shown in Figure 4.

Interference to the ERSOS earth station from the airborne SHF SATCOM transmitter is predicted to occur when:

$$S - I \leq (S/I)_{MINIT} \text{ protection ratio} \qquad (9\text{-}2)$$

where

S = the desired received carrier power, which is the SNR + N for ERSOS, in dBm

I = the undesired interference power as computed in dBm

$(S/I)_{MINIT}$ = the signal-to-interference protection ratio for RBV camera data from Table 27 in dB

Equations 9-1 and 9-2 can be combined, rearranged and solved for either the loss L_{FS} required, for no interference (with no OFR) or for OFR values

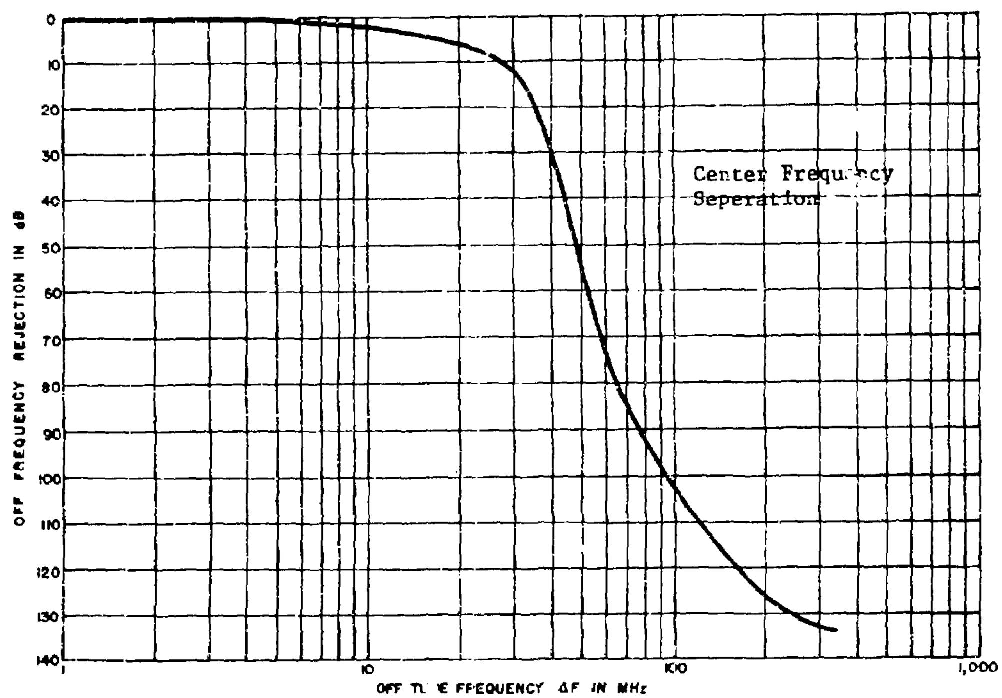


FIGURE 110 ASC-18 TRANSMITTER TO ERSOS WIDEBAND RECEIVER OFF TUNE FREQUENCY REJECTION CURVE

with selected separation distances. For the third situation, a separation distance is selected and the OFR values for various off-axis gain values for the ERSOS antenna are calculated.

The ERSOS main beam coupling to SHF for 10 kW of transmit power peak sidelobe calculation indicated that the propagation loss required for no interference was 225 dB. With the airborne SHF SATCOM terminal at 24,000 feet msl altitude, the no-interference separation distance was beyond the line-of-sight. Since a power level restriction for the airborne SHF SATCOM terminal operation may not be desirable, frequency separation could be considered as a means of reducing the potential for interference to the ERSOS earth station. The path loss from the ERSOS earth station pointing to an aircraft at 24,000 feet (msl), which is operating in an area adjacent to the ERSOS 5° elevation tracking volume, is predicted to be 144 dB (42 nm). Frequency separation of 94 MHz is predicted to reduce the received interference signal level at the ERSOS station to the permissible interference threshold of -102 dBm.

Since protecting the ERSOS main beam from interference requires such large restriction area or frequency separation for airborne SHF SATCOM terminal operation it is informative to estimate the probability of main beam encounter when an aircraft penetrates the ERSOS tracking volume.

The probability of an aircraft intercepting the ERSOS main beam while on a random overflight can be estimated from a ratio of the main beam window to the tracking airspace at 24,000 feet msl and the ERSOS satellite visibility period for Sioux Falls, South Dakota. The airspace viewed from a 5° elevation tracking angle has a 42 nm radius at 24,000 feet msl. The main beam window at the edge of the 42 nm circular airspace

is approximately 0.21 nm in diameter (for the ERSOS 0.28° beamwidth).

The area ratio can be calculated as follows:

$$\frac{(0.21 \text{ nm diameter})^2}{(84 \text{ nm diameter})^2} = 2.5 \times 10^{-5}$$

The ERSOS satellite visibility for data acquisition at Sioux Falls, South Dakota can provide five passes per day, each of which is about ten minutes in duration. The dedicated earth station visibility factor can be calculated as follows:

$$\frac{(5 \times 10 \text{ minutes})}{(1440 \text{ minutes})} = 3.5 \times 10^{-2}$$

The probability of main beam interception for a single overflight through the Sioux Falls, South Dakota tracking volume is 8.7×10^{-7}. Thus a single overflight has a probability of intercepting the ERSOS main beam of less than one in a million.

If the ERSOS antenna were pointing at a low elevation angle and the airborne SHF SATCOM terminal happened to intercept the main beam, the maximum duration of the interference would be less than two seconds.

OFF-AXIS ANTENNA COUPLING

The airborne SHF SATCOM terminal operational restrictions in the area near Sioux Falls, South Dakota can be reduced from those presented above if the off-axis coupling characteristic of the ERSOS 30 foot antenna is considered.

Probability Off-Axis ERSOS Coupling - A band sharing situation is presented here which involves a smaller ERSOS tracking volume to be protected and a consequently smaller area to be restricted for the airborne SHF SATCOM

terminal operation. For example, assume that the minimum tracking elevation angle (for the ERSOS earth station) to be protected from interference on a continuing basis is 9°. Whether or not restricting the ERSOS data acquisition to a minimum tracking angle of 9° would have any significant impact on ERSOS data collection should be explored with the Department of the Interior/NASA agencies.

The off-axis antenna coupling angle from the ERSOS antenna to the airborne SHF SATCOM terminal will be assumed to be maintained at 2° or more at all times for protection considerations. This allows the airborne SHF SATCOM terminal to operate in areas adjacent to a 30 nm radius, centered on the Sioux Falls coordinates of 43°32'31"N and 96°45'428"W (see Figure 111). A peak gain or antenna coupling value for 2° to 3° off axis was assumed to be plus 10 dBi. This reduces the path loss requirement from '25 dB to 180 dB which is predicted to protect the ERSOS earth station from 10 kW co-channel operation of the airborne SHF SATCOM terminal.

Aircraft flight test data indicates that coupling values for the airborne SHF SATCOM antenna at 24,000 feet will be -1 dBi when the aircraft is to the northeast from the ERSOS earth station, -8 dBi when the aircraft is to the north or south, and -13 dBi when the aircraft is to the west. With the aircraft operating to the northeast in areas adjacent to the 30 nm radius from Sioux Falls, South Dakota, frequency separation can reduce the possible received interference to permissible levels. To protect the ERSOS downlink when it is tracking in the northeast direction, the following center frequency separation should be maintained for airborne SHF SATCOM channels:

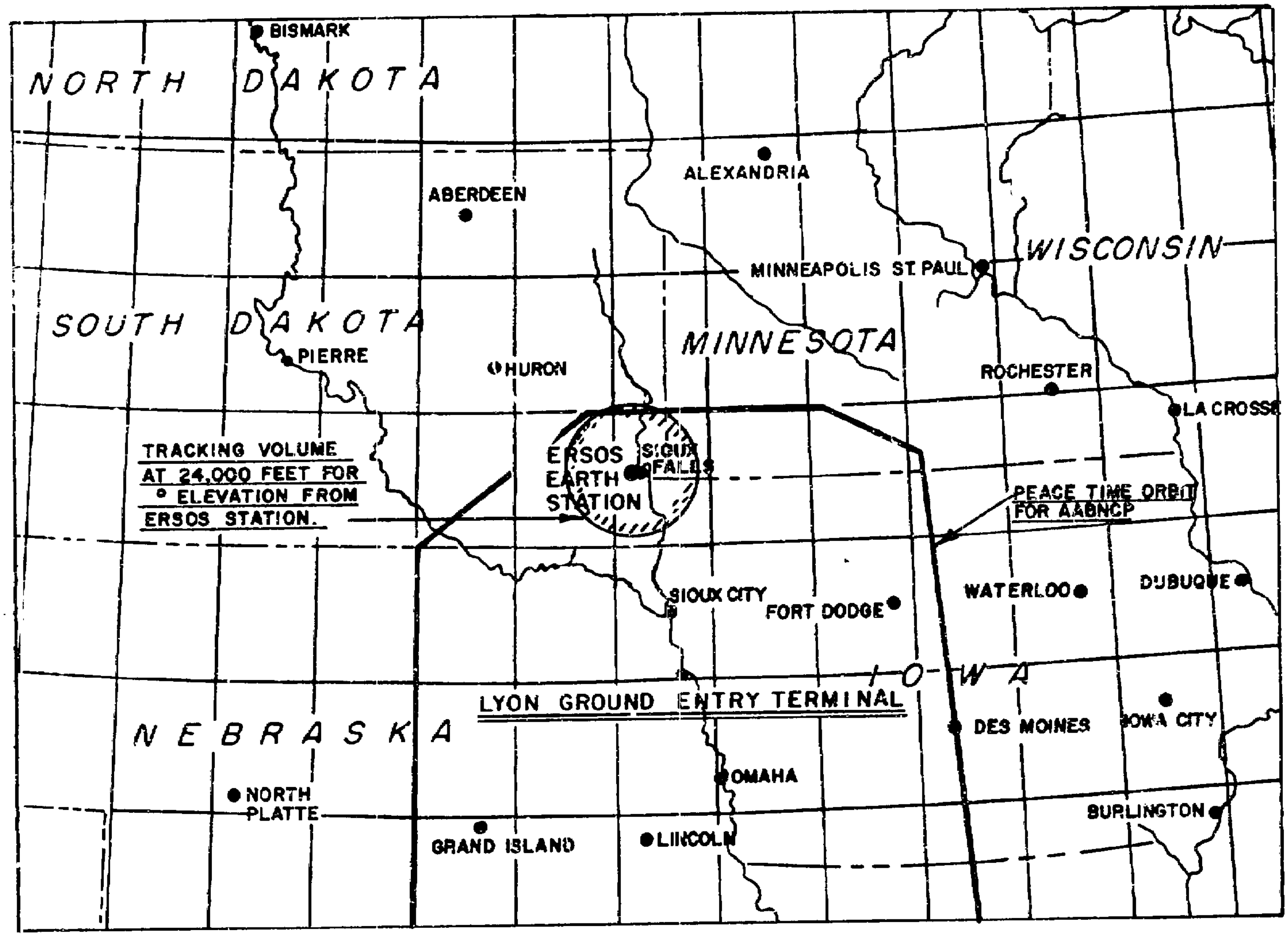


FIGURE 111 PROTECTION ENVELOPE FOR ERSOS EARTH STATION

35 MHz for 100 watts

40 MHz for 1 kW

44 MHz for 10 kW

When the airborne SHF SATCOM terminal operates in the quadrants around Sioux Falls other than the northeast, the frequency separation can be reduced as follows:

For the northwest and southeast:

29 MHz for 100 watts

36 MHz for 1 kW

41 MHz for 10 kW

For the southwest quadrant:

20 MHz for 100 watts

34 MHz for 1 kW

38 MHz for 10 kW

One final situation for frequency sharing can be suggested after considering the low probability for an aircraft encountering the ERSOS antenna main beam while flying through the tracking volume. Frequency separation of 44 MHz will reduce potential interference to the ERSOS earth station from the airborne SHF SATCOM terminal at 10 kW of transmit levels for the 2° or 3° off-axis coupling situation even during overflight. This leaves only the ERSOS main beam area for interference reception and the probability of an aircraft intercepting the 30 foot antenna main beam is very unlikely.

CONCLUSIONS*

1. No interference with the ERSOS system is predicted when the airborne SHF SATCOM terminal operates beyond line-of-sight from the ERSOS earth station at any transmit power level or frequency.

2. When the airborne SHF SATCOM terminal is at separation distances of 30 nm from the ERSOS earth station at least 44 MHz of frequency separation is required to avoid possible interference if 10 kW of transmit power is used.

3. Interception of the ERSOS main beam by an aircraft flying through the ERSOS tracking volume is very unlikely.

4. For direct overflights above the ERSOS earth station a 50 MHz frequency separation is predicted to permit 10 kW operation with a very low probability of interference to ERSOS data acquisition.

5. The above restrictions are for the most susceptible channel which is RBV. The MSS and TLM channels have greater protection.

RECOMMENDATIONS

1. It is recommended that the airborne SHF SATCOM terminal restrict its operation from an area of approximately 30 nm radius centered on Sioux Falls, South Dakota once the ERSOS earth terminal becomes operational.

2. It is recommended that when the airborne SHF SATCOM terminal operates within line-of-sight of an ERSOS earth station that approximately 44 MHz of frequency separation be maintained.

*See Assumptions in SECTION II.

SECTION X

OTHER SYSTEMS ANALYSIS

GENERAL

There are a number of other microwave systems which could be effected by the airborne SHF SATCOM terminal operation in the air or on the ground. The effects on these systems were analyzed[3] by calculations or comparison with systems described in SECTIONS V through IX. The analysis was based on the assumptions in SECTION II and on frequency assignments as of May 1974. Separate calculations of the effect of ground operation was accomplished.

CONCLUSIONS OF ANALYSIS ON OTHER MICROWAVE SYSTEMS

Analysis of the following four microwave systems indicates that no serious interference is expected from the airborne SHF SATCOM terminal.

DOD Users - DOD terrestrial microwave users have links which are very similar to the TVA's 600-channel FM voice links. Therefore, the TVA conclusions appear to apply to the DOD users. That is, the amount of interference expected from the E-4 SHF SATCOM system appears to be small compared with the natural outages which occur on the links in the absence of SHF SATCOM interference signal. However, if long haul non-diversity transportable links are deployed during a contingency operation, there is a potential for interference.

TDRSS - The Tracking and Data Relay Satellite System (TDRSS) has a revised frequency plan which no longer contains operational frequencies of concern in the same band as the airborne SHF SATCOM system. Therefore, no interference is expected.

MSS-GOES - The Meteorological Satellite System which is planned for the late 1970s plans to operate in the 8 GHz region. Operation of this system is an uplink from a ground station to a satellite. Since this uplink frequency falls in the guard band between DSCS-II frequencies, there appears to be no problem of interference.

FLEETSATCOM - The Navy's FLEETSATCOM broadcast station will operate an uplink in the exclusive band of the DSCS-II frequency allocation.

Since this signal is an uplink signal and since the satellite will be located at some distance from the DSCS-II satellite, no interference is expected for the airborne SHF SATCOM system.

AIRBORNE SHF SATCOM GROUND OPERATION

General - Often it will be necessary to operate the airborne SHF SATCOM transmitter while the E-4 aircraft is on the ground. This will be done while the aircraft is on alert, preparing to depart for a flight or for various maintenance and training activities. When operating in this manner, the airborne SHF SATCOM will be functioning as a Small Earth Terminal (SET). Coordination procedures and band sharing constraints for operation of such systems (SET's) are presently being formulated in various study groups of the IRAC and CCIR. When finalized, these procedures should be applied to the selection of operational locations, frequencies and power levels for the E-4 ground operations. At present, the number of air bases which might be equipped for E-4 operations is large and deployment plans have not been finalized. It is likely that extensive operations will be conducted out of Offutt AFB, Omaha, Nebraska and Andrews AFB, Maryland.

This section presents a method of identifying FDM/FM systems in the vicinity of the E-4 ground operational location which must be examined in order to determine if the system will experience interference. In order to ensure that all possible interference victims are considered, a set of parameters was chosen which presents the worst case interference situation. The computations are presented so that maximum use can be made of the data in the IRAC frequency assignment files (location, frequency, bandwidth and antenna orientation) in order to eliminate from further consideration systems with which no interference is anticipated.

FDM/FM Equipment Characteristics - The characteristics of the victim microwave equipments were selected based upon examination of a number of different nomenclatures which are common in the environment. The IF bandpass characteristics were found to be typified by a six element Butterworth filter with the far out attenuation characteristics modified by the effects of an RF filter. A typical curve for a 20MF9 receiver is presented in Figure 112. For the basic computation, the receivers are assumed to be using a 45 dBi gain antenna at a height of 200 feet and to have a 12 dB noise figure (-90 dBm in a 20 MHz IF). The worst case gain values for various angles off the main beam are given in Table 28.

TABLE 28

FDM/FM ANTENNA CHARACTERISTICS

DEGREES OFF MAIN BEAM AZIMUTH	FDM/FM ANTENNA GAIN (dBi)
±1	45
1-5	30
5-10	20
10-20	10
20-100	0
100-180	-10

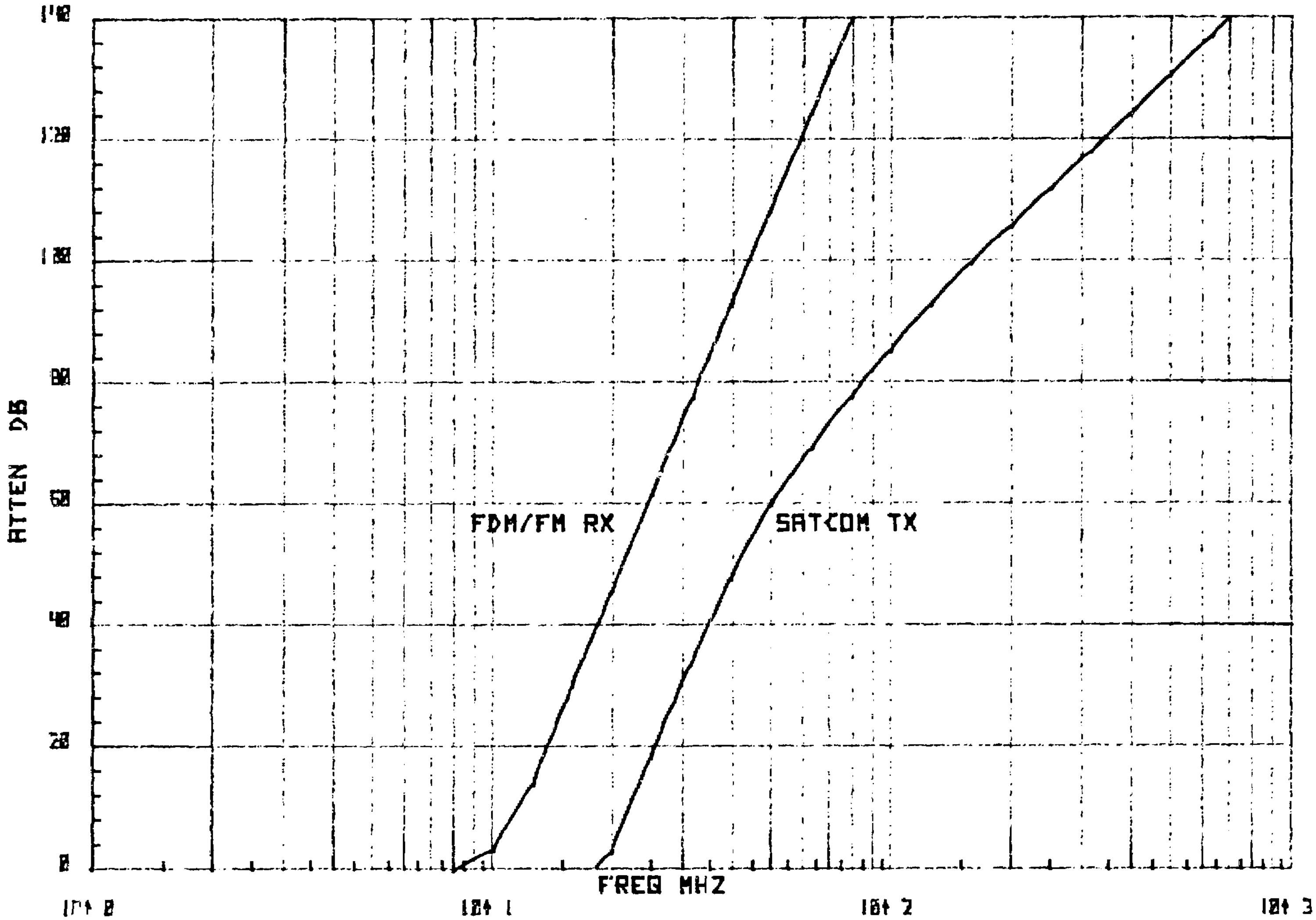


FIGURE 112 RECEIVER BANDPASS AND TRANSMITTER OUTPUT SPECTRUM

SHF SATCOM Characteristics - The output spectrum of the airborne SHF SATCOM transmitter was measured by AFAL[33] and presented in Reference 3. It is redrawn and presented in Figure 112.

Since this study is to develop a culling process, the airborne SHF SATCOM antenna is assumed to have somewhat higher sidelobes than those presented in APPENDIX A. This is done to ensure no systems are overlooked. These worst case gain values are given in Table 29. The minimum antenna elevation will be 10 degrees.

TABLE 29

AIRBORNE SHF SATCOM ANTENNA GAIN

DEGREES OFF MAIN BEAM AZIMUTH	ANTENNA GAIN (dBi)
0-20	+5
20-100	0
100-180	-5

The height of the airborne SHF SATCOM dish at its planned location atop of the E-4 fuselage is approximately 30 feet.

Frequency and Distance Separation Plots - A standard automated ECAC routine[23] was used to determine frequency and distance separation requirements. The routine uses the receiver bandpass characteristics and transmitter spectrum to determine the amount of rejection to the unwanted signal for various degrees of off tuning. This rejection is then compared to a specified total rejection value to determine the amount of propagation loss needed to preclude interference. The propagation model is then examined to determine the distance separation which will produce the required loss. The propagation model used considers no terrain blockage other than that due to earth curvature and assumes multipath reinforcement is occurring.

The total loss mentioned above (L_T) is determined from the worst case parameters and is given in the following equation:

$$L_T = P_T + G_T + G_R - I_R$$

$$= 70 \text{ dBm} + 5 \text{ dBi} + 45 \text{ dBi} - (-90 \text{ dBm}) = 210 \text{ dB} \qquad (10\text{-}1)$$

where

L_T = total required loss (dB)

P_T = airborne SHF SATCOM power output (dBm)

G_T = airborne SHF SATCOM antenna gain (dBi)

G_R = FDM/FM antenna gain (dBi)

I_R = interference threshold (dBm)

Note that for culling purposes, an interference threshold equal to the receiver noise level has been used. If problems are flagged, then consideration should be given to such factors as hop distances, desired signal levels, required performance requirements, etc., in a manner similar to that used in this report to analyze airborne operations.

Plots of the relationship of off tuning to separation distance were generated for five receiver bandwidths (45, 25, 20, 15 and 10 MHz). Each plot shows the relationship for nine levels of total loss (Figures 113 through 117).

Along with variations in transmitter power (P_T) and receiver interference sensitivity (I_R), the relative pointing angles of the two antennas will determine the required loss value. The values of G_T and G_R in Equation 10-1 are combined in Table 30 and presented as a single value G_m for various pointing angles.

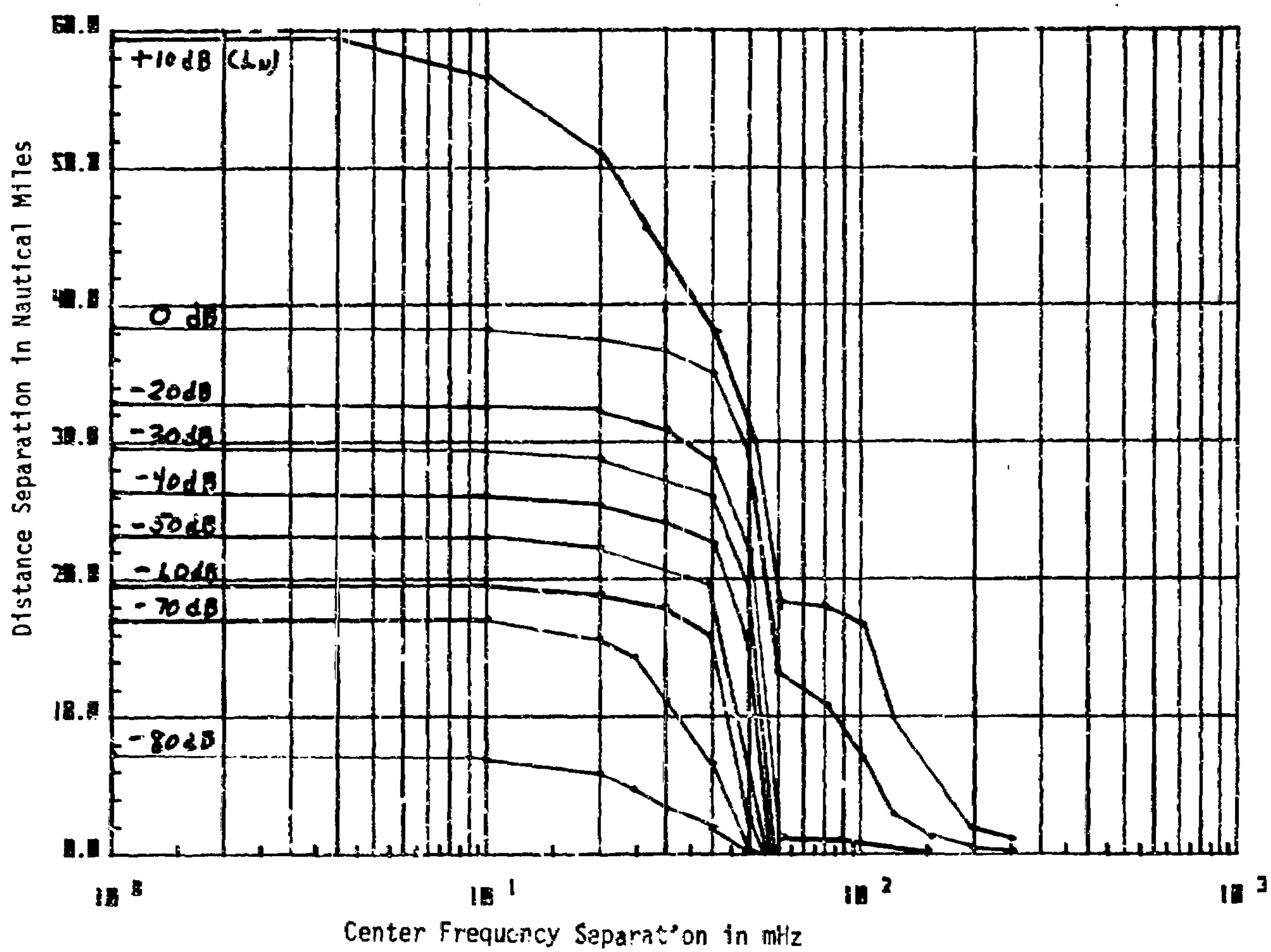


FIGURE 113 FREQUENCY SEPARATION VS DISTANCE SEPARATION FOR NORMALIZED LOSS (45MF9 RECEIVER)

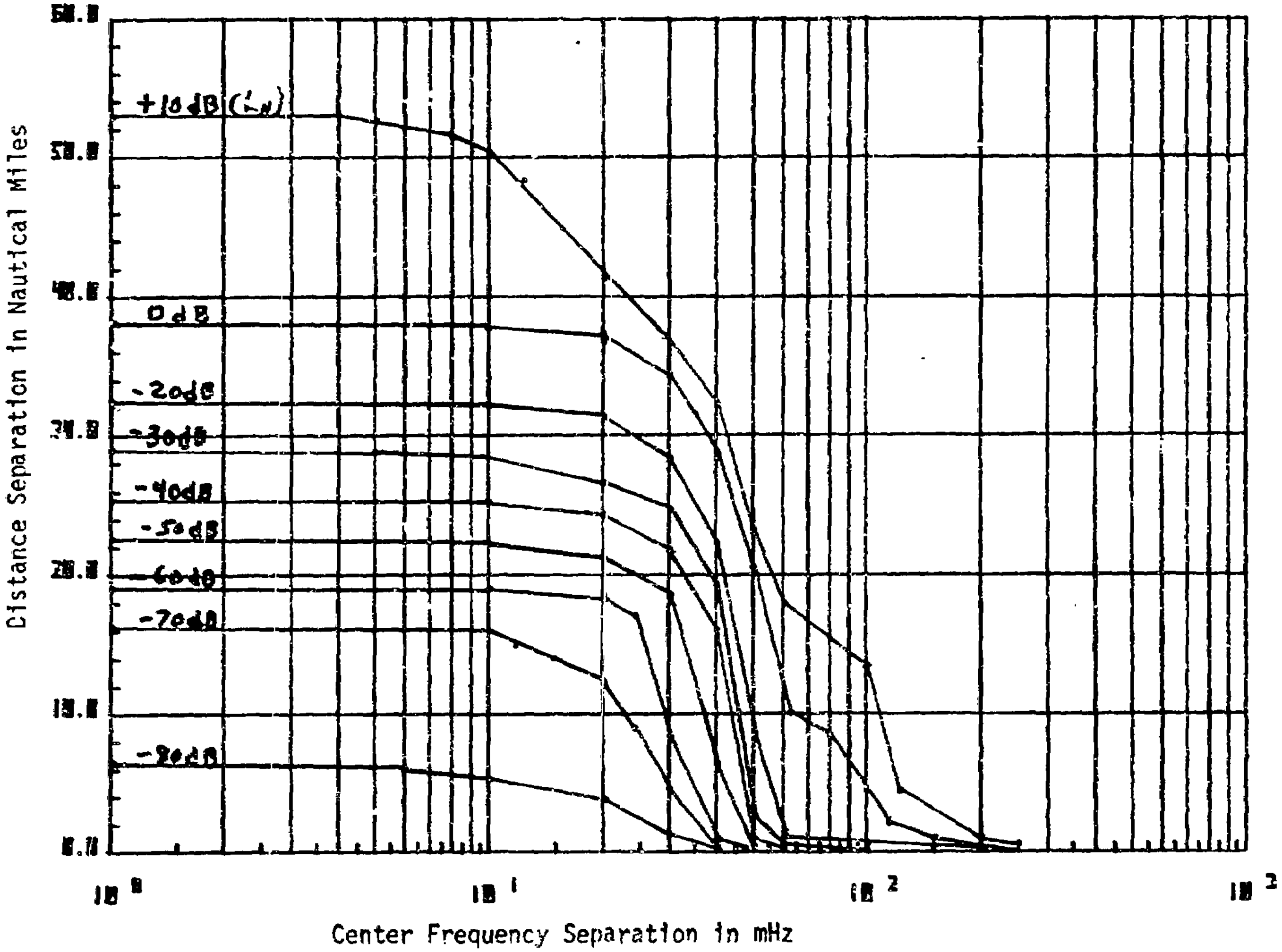


FIGURE 114 FREQUENCY SEPARATION VS DISTANCE SEPARATION FOR NORMALIZED LOSS (25MF9 RECEIVER)

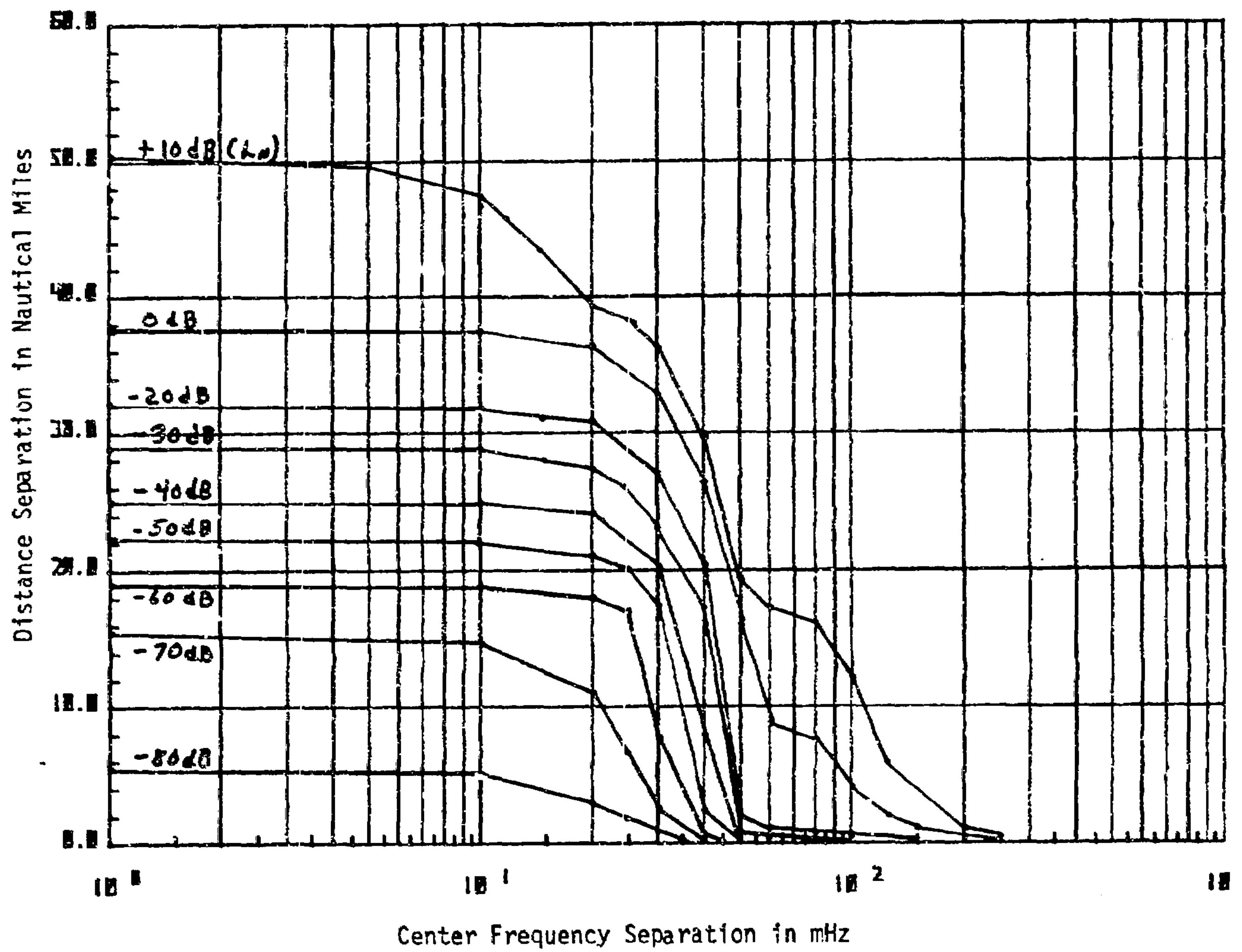


FIGURE 115 FREQUENCY SEPARATION VS DISTANCE SEPARATION FOR NORMALIZED LOSS (20MF9 RECEIVER)

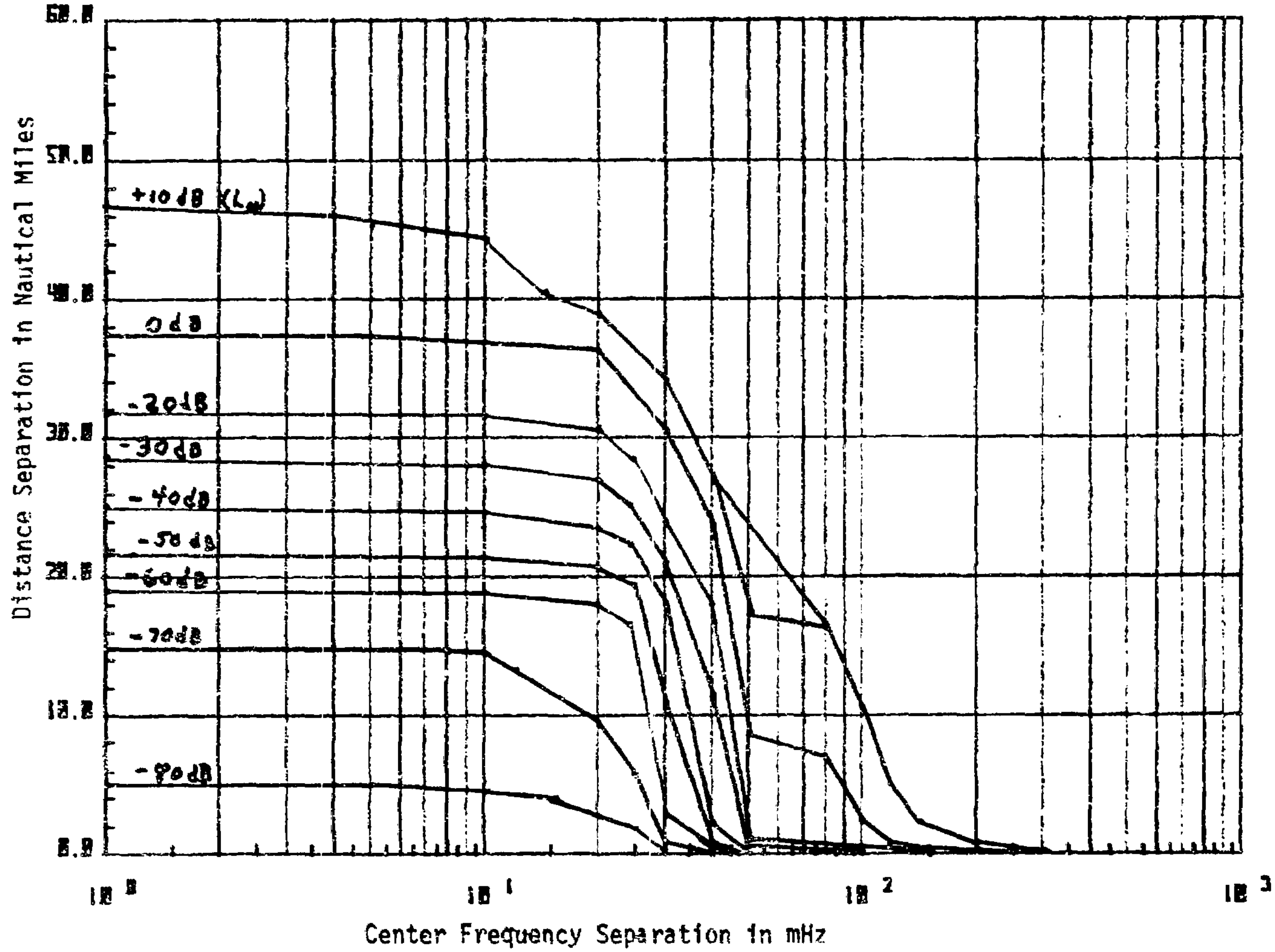


FIGURE 116 FREQUENCY SEPARATION VS DISTANCE SEPARATION FOR NORMALIZED LOSS (15MF9 RECEIVER)

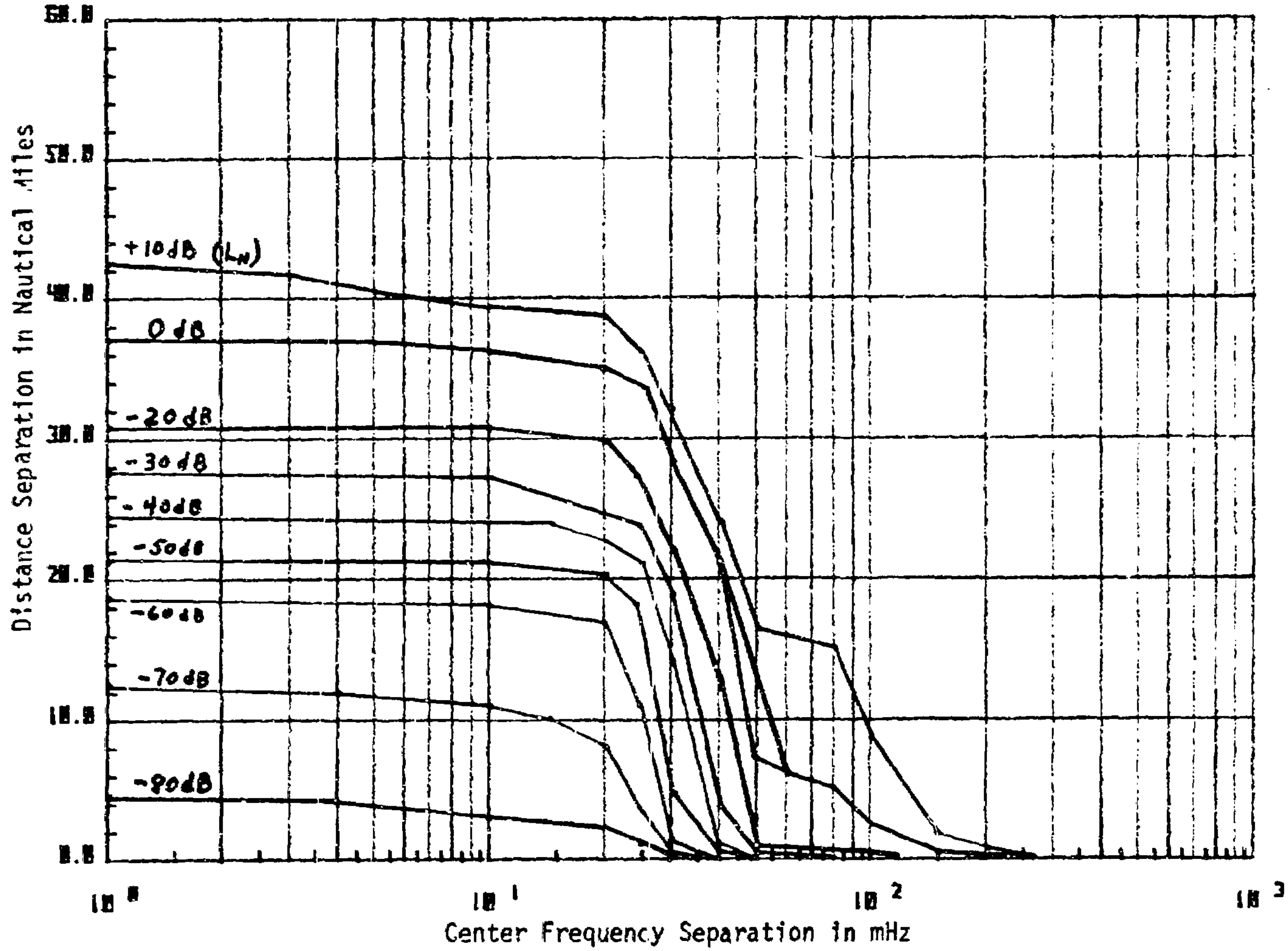


FIGURE 117 FREQUENCY SEPARATION VS DISTANCE SEPARATION FOR NORMALIZED LOSS (10MF9) RECEIVER

TABLE 30

MUTUAL ANTENNA GAIN (G_m), dBi

		FDM/FM Az off Main Beam (degrees)					
		±1°	1°-5°	5°-10°	10°-20°	20°-100°	>100°
Airborne SHF SATCOM	0-20°	50	35	25	15	5	-5
Antenna AZ off Main	20-100°	45	30	20	10	0	-10
Beam in Degrees	100-180°	40	25	15	5	-5	-15

The range of interference power levels are seen to vary over 65 dB due to antenna orientation. Due to probable use of lower airborne SHF SATCOM transmitted powers and possible introduction of more sensitive receiver in the environment, a total range of 90 dB will be considered in this analysis.

The nine plots on each graph are labeled from +10 to -80 dB of normalized loss (L_n). The proper curve to be used is determined by solving Equation 10-1 relative to the main beam case loss (L_T).

$$P_T + G_m - I_R - 210 = L_n$$

The analysis presented here does not consider what are called cosite effects, image, spurious and intermodulation response, desensitization, etc. Any equipment operating within one mile of the site should be given separate consideration since it is not covered by this approach.

Examination of the worst case curves, Figure 113, indicates that the environment within 60 nm of the site should be subjected to the cull process over a frequency range of $\pm$100 MHz from the airborne SHF SATCOM tuned frequency. For each system identified with the culling distance, the L_n must be computed. Then the appropriate graph is entired at the actual distance and frequency separation. If the intersection of the two values is to the right or above the appropriate L_n plot no problem exists. If it is to the left, then some further analysis is necessary. The first step should be to investigate the value I_R or interference criteria. If, for example, the microwave path is very short, consideration could be given to changing the amount of interference which could be tolerated. In addition, consideration should be given to terrain shielding, required signal-to-interference ratios, etc.

Site Analysis - In order to test the effectiveness of the cull process, the environment within 100 miles of Offutt and Andrews AFB's was examined, within $\pm$100 MHz of a hypothetical airborne SHF SATCOM frequency.

No systems were found in the vicinity of Offutt AFB which fell within frequency and distance constraints.

Twenty-four systems (excluding other space systems) were identified around Andrews AFB. Of these, the culling procedure eliminated 17 from further consideration. Of the seven remaining systems, four operate over very short transmission paths and an appropriate modification of the interference threshold level eliminates them as potential problems. Two other systems were eliminated based upon the additional path loss due to terrain effects. Only one system remained which would require a thorough analysis to determine the seriousness of the interaction and the best course of action for resolution of the problem.

In addition to the analysis of specific sites, potential interference problems could also be created by a transmission from the aircraft during take-off (or landing) flight paths in the immediate vicinity of the airport. That is, for certain mission requirements it may be necessary to have continuous transmission and lock-in with the satellite as the aircraft changes from airport to take-off to in-flight (or reverse) locations. During take-off and before the aircraft has reached cruising altitude, potentially strong, but short, interference coupling situations could be encountered which should be investigated as part of the airport site analysis.

SUMMARY

The findings of this ground operation study are summarized below:

1. Consideration should be given to the environment within 60 miles of an E-4 base of operation with $\pm$100 MHz of the planned airborne SHF SATCOM frequency.

2. The culling process using the frequency vs distance curves presented in this section could be used when investigating E-4 operating bases and satellite frequencies.

3. The potential interference problem caused by continuous transmission during take-off should be included as part of the airport site analysis investigations.

APPENDIX A

AIRCRAFT ANTENNA MEASUREMENTS

INTRODUCTION

The SHF SATCOM system for the Aavanced Airborne Command Post aircraft transmits in the 7.9 to 8.4 GHz band. Various government ground microwave links (FAA, TVA, AEC, etc.) use the same frequencies, consequently the SHF SATCOM system is a potential interference source. The aircraft antenna will always be pointed upward toward the DSCS satellites, hence the main beam should not illuminate the ground-based victims. Therefore, potential interference signals will be radiated from the side and backlobes of the aircraft antenna. To obtain better estimates of the aircraft antenna characteristics, a series of airborne measurements were conducted[31] using the facilities of the Air Force Avionics Laboratory (Wright-Patterson AFB, Ohio) and the 4950th Test Wing C-135 SATCOM testbed aircraft. The rationale for scheduling airborne tests to obtain additional antenna pattern data was twofold: (1) data could be obtained for various pointing angles and aircraft headings that would tend to overcome multipath problems normally experienced during ground-based tests; and (2) information could be gathered regarding possible shielding effects of the aircraft as it passes over a potential interference victim. This latter part is of particular interest since numerous microwave systems in the 7-8 GHz band employ periscopic antenna configurations. On 27 February 1975 the aircraft (Figure A-1) equipped with the ASC-18 SHF SATCOM Terminal flew a prescribed pattern to obtain measurements at numerous relative angles. The SHF antenna under investigation is shown in Figure A-2. Flight test radar provided

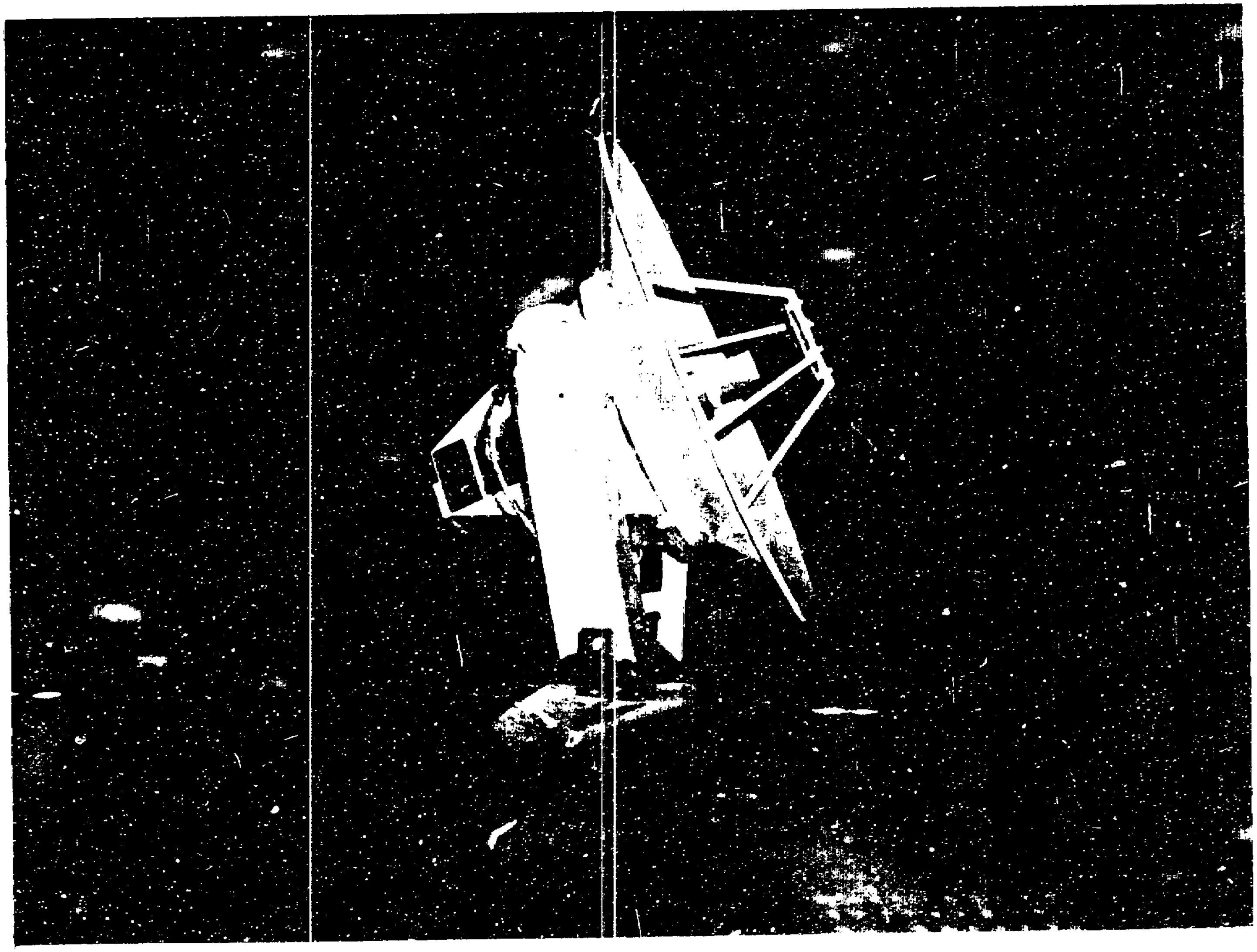


Figure A-1. SHF SATCOM Testbed Aircraft C135B/12662

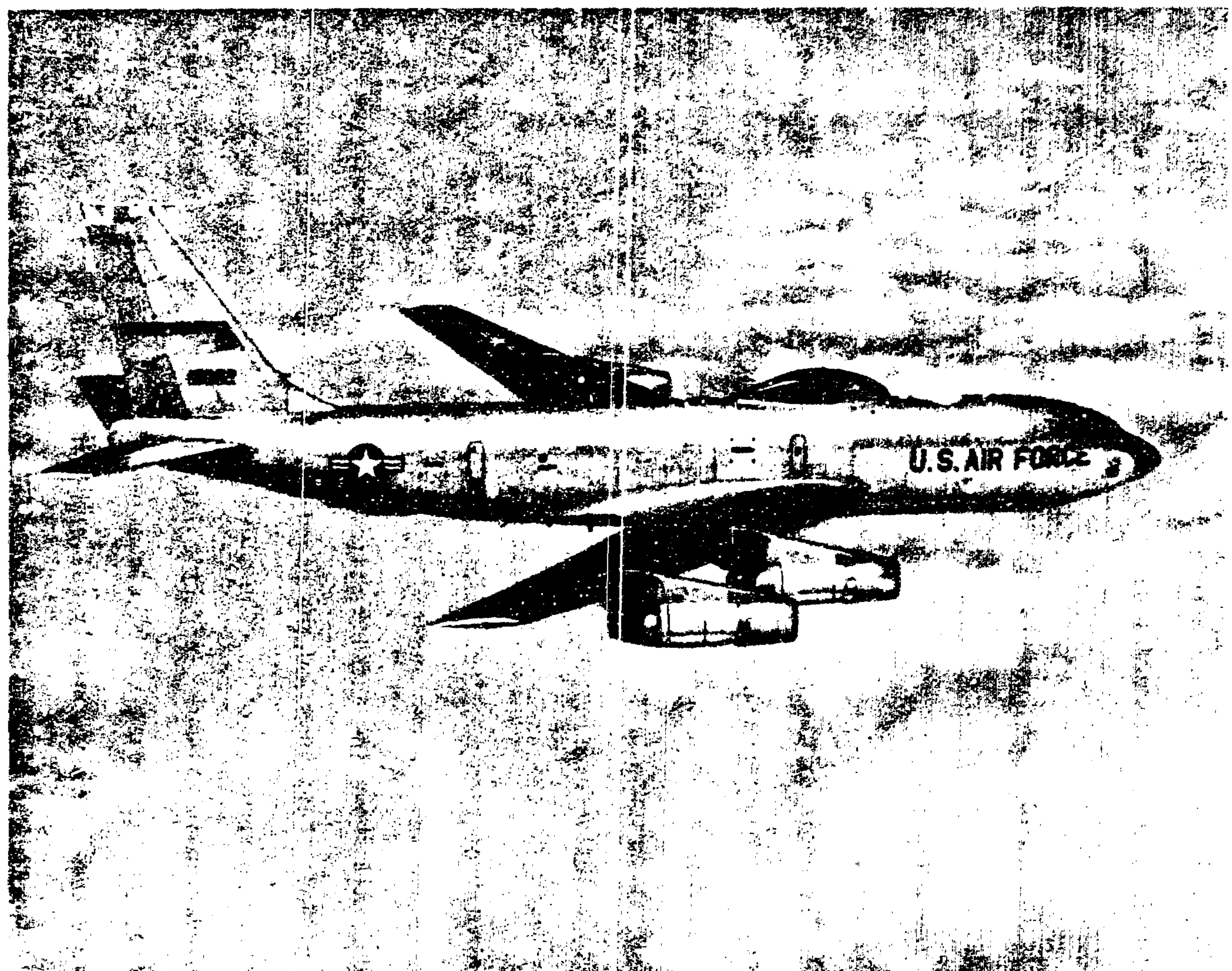


Figure A-2. SHF SATCOM Airborne Antenna

aircraft positional information. Additional measurements were taken on 5 May and during the Jacksonville FAA test of 19-20 May 1975.

AIRCRAFT ANTENNA SIDELOBE PATTERNS

To determine the sidelobe structure for distances greater than 30 nautical miles, three parameters were varied as signal strength was recorded.

(1) The angle from the nose of the aircraft to the ground receiver is defined as the relative bearing to the ground receiver. Angles chosen were 0° (over the nose), 30°, 90°, 120° (over the wing), 150° and 180° (over the tail).

(2) The angle of the aircraft antenna relative to the aircraft nose is defined as the antenna azimuth. For each given relative bearing, the antenna was rotated at a constant rate in azimuth. Each rotation provides one cut of the antenna pattern. Five rotations comprised each sample as defined by relative bearing and elevation.

(3) The aircraft antenna elevation was also set to a new value after azimuth rotation was completed at a given relative bearing. The elevation angle was changed and the azimuth rotation repeated.

Figure A-3 shows the antenna pattern measurements with a relative bearing of 90°. This produced the strongest signal and will be used as the standard pattern. Note how the sidelobes around the main beam diminish as the elevation is raised. In particular, note that except for the first sidelobe of the main beam, all sidelobes are from 0 dBi (RHCP) to -25 dBi (RHCP) referenced to a circularly polarized isotropic source. The -25 dBi (RHCP) is the noise floor limit of the test aircraft. Other relative bearings have aircraft blockage, reducing the sidelobe gain below that of the 90° relative bearing plots.

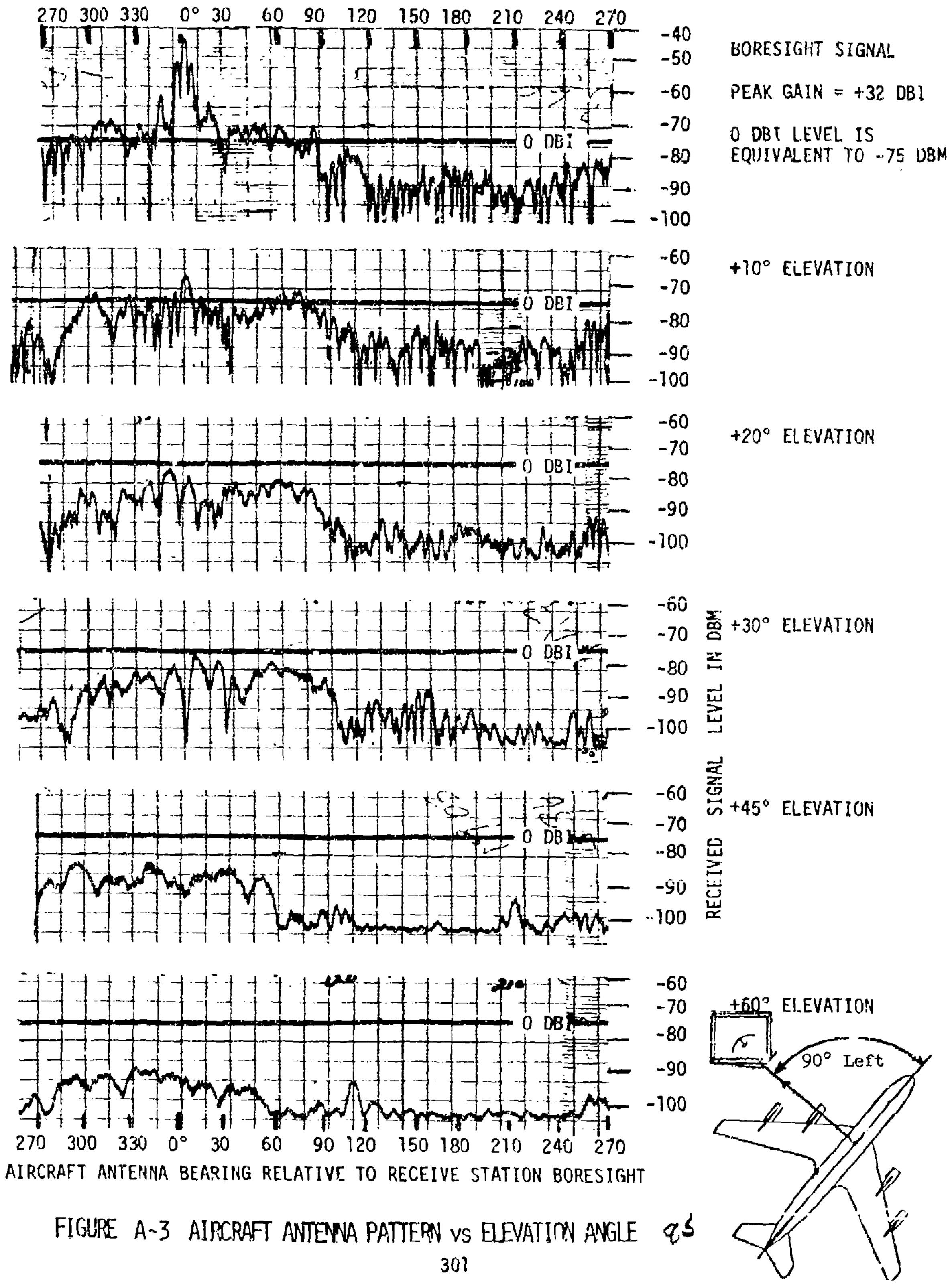


FIGURE A-3 AIRCRAFT ANTENNA PATTERN vs ELEVATION ANGLE

A polar plot of the estimated average of the 90° relative bearing data for different azimuths and elevations is shown in Figure A-4. This is a useful general summary of the gain relative to an isotropic source.

AIRCRAFT SHIELDING AT CLOSE DISTANCES

Any aircraft shielding of the SHF signal would be of great importance in reducing potential interference to a ground station. The amount of shielding experienced was investigated as a function of distance between the aircraft and ground site. This shielding was expected to vary according to whether the blockage was by the aircraft nose, wing, tail or fuselage. Therefore, three types of shielding tests were performed.

(1) Inbound overhead passes beginning 50 nautical miles away were flown to determine nose and fuselage blockage.

(2) Short overhead passes 10 nautical miles long, centered above the ground station were flown to refine fuselage and tail blockage.

(3) The effect of wing blockage and fuselage blockage off the side of the aircraft was investigated by flying the aircraft straight and level but offset from overhead of the station. The received signal strength was converted to isotropic gain by correcting for distance (different space loss) and the receive antenna pattern.

The first overhead pass was flown on 27 February 1975. The antenna was pointed over the aircraft nose toward the ground station. Antenna elevation was 45° The vertical profile of this flight path is shown in Figure A-5. The peak received signal strength for the overhead path is shown in Table A-1 and the data points are plotted as dots in Figure A-6. Due to the multipath scalloping of the received signal strength, an envelope touching the peaks was used as the signal level for this and all other plots.

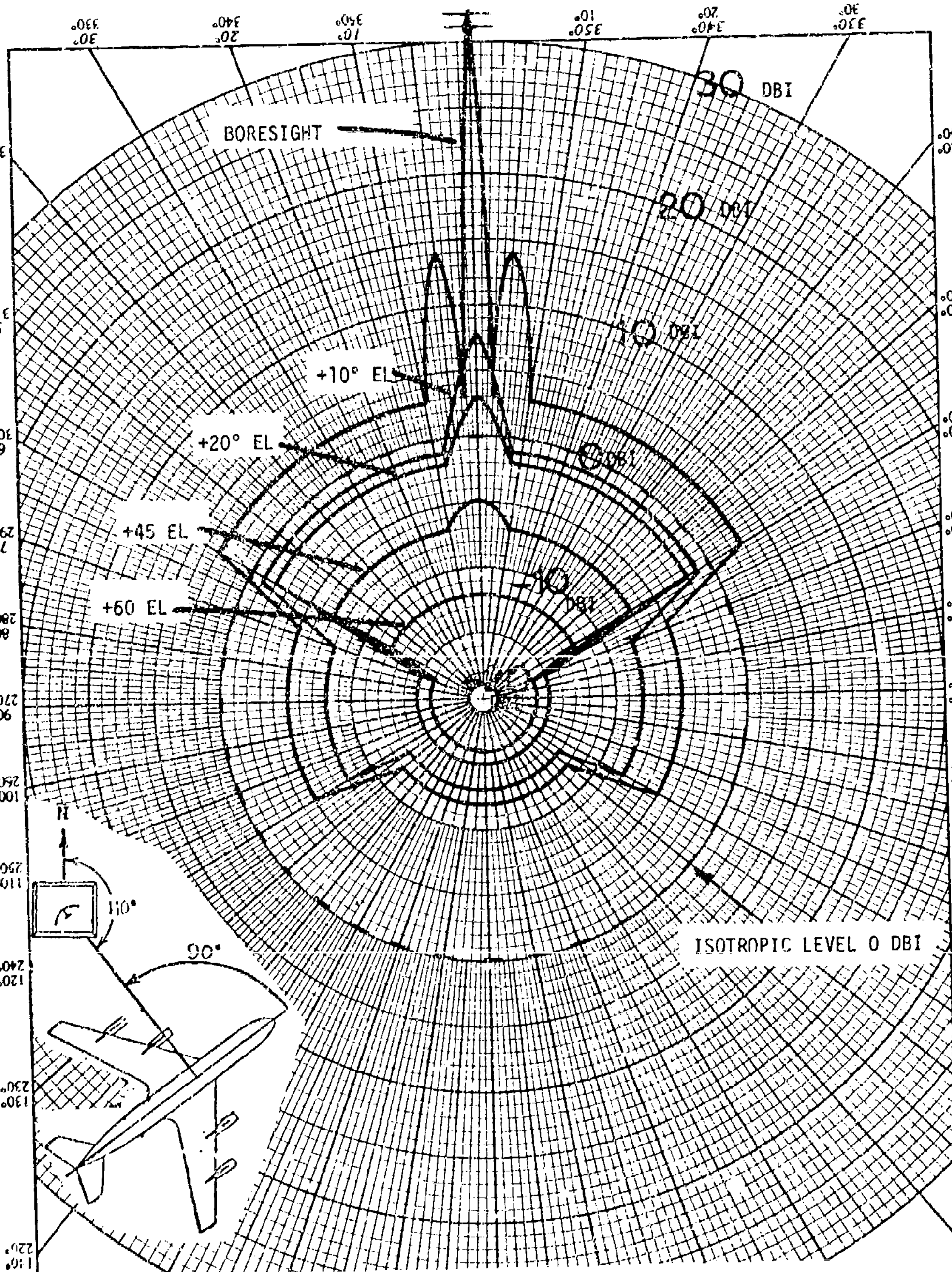


FIGURE A-4 AIRCRAFT ANTENNA GAIN ENVELOPE vs ELEVATION ANGLE

ANTENNA AZIMUTH 360° (towards aircraft nose)

ANTENNA ELEVATION +10° on 5 May 1975

+45° on 27 Feb. 1975

RELATIVE BEARING TO GROUND STATION 0° (towards station)

TRANSMITTER POWER 10 Kw

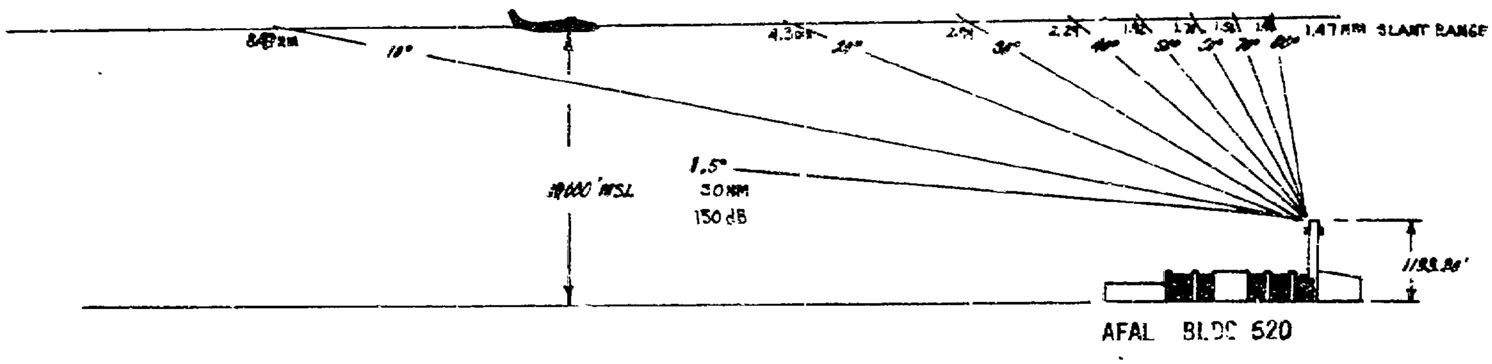


Figure A-5. Vertical Profile of Overhead Passes

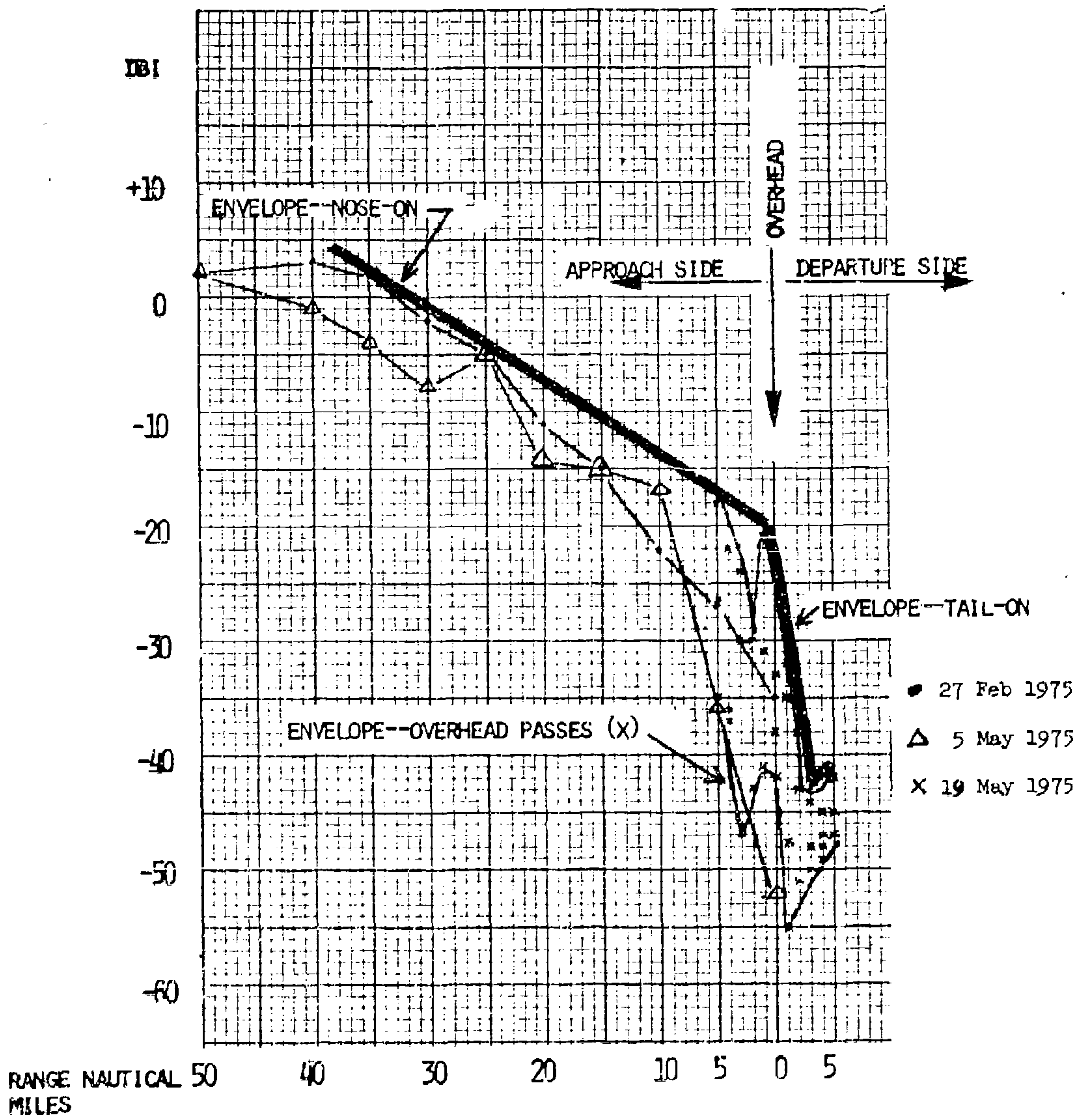


FIG. A-6 A/C ANTENNA PATTERN-- OVERHEAD, NOSE -ON AND TAIL-ON

TABLE A-1

NOSE-ON OVERHEAD FLIGHT TEST DATA

RESULTS			CORRECTION FACTORS		
DISTANCE (NM) HORIZONTAL/ SLANT RANGE	RAW SIGNAL LVL RECEIVED (dBm)	ANTENNA GAIN REL TO ISO-TROPIC (RHCP) (dBi)	FREE SPACE LOSS: FREE SPACE LOSS	FREE SPACE LOSS: REL TO 50 NM	REC LVL REL TO THE PEAK OF THE MAIN BEAM - MAIN BEAM PEAK -50 dBm
50/50	Main Beam -50	+32	150	0	0
50/50	-80	+2	150	0	-30
40/40	-77	+3	148	-2	-27
35/35	-77	+2	147	-3	-27
30/30	-79	-1.5	145.5	-4.5	-29
25/25	-80	-4	143.8	-6.2	-30
20/20	-85	-11	142	-8	-35
15/15.07	-85	-13	139.5	-10.5	-35
10/10.11	-90	-21.5	136.5	-13.5	-40
5/5.21	-90	-27.5	130.5	-19.5	-40
overhead 1.47	-85	-35	118	-32	-35

Isotropic Gain - Main Beam Gain - Sidelobe Level Relative to Peak + a Distance Correction

On 5 May 1975 an additional overhead pass was made with the aircraft antenna elevation at +10° This is plotted as triangles in Figure A-6.

To further define the aircraft fuselage shielding, the aircraft was flown directly overhead of the field intensity receiver set up at the FAA Seales RML-4 site near Jacksonville, Florida. Then a series of overhead passes were flown with the aircraft approaching from different directions. The aircraft antenna in these passes was at +10° elevation and pointed at the nose of the aircraft. This data is plotted as a field of x's with boundaries in Figure A-6. Note that when the tail of the aircraft is toward the ground receiver (aircraft antenna is still looking forward) the SHF signal is significantly blocked by the tail structure.

The offset passes were flown nominally at distances 2, 5 and 10 nautical miles offset from the ground station. The envelope of the peak signal received for a given offset run is plotted in Figure A-7. These were for the approaching portion of the offset run.

After passing abeam, the received signal dropped abruptly, similar to the "tail-on" portion of the overhead passes shown in Figure A-6. The gain during the departure side varied from -25 dBi to -50 dBi, and is not shown on Figure A-6.

The gain envelope will be conservatively taken to be the composite peak envelope of offset envelope gains. This is shown as the heavy line in Figure A-7.

CONCLUSIONS

The sidelobe structure varies from 0 dBi (RHCP) to at least -25 dBi (RHCP), except for the first sidelobes which are 12 to 15 dB below the main beam. As the elevation of the antenna is increased, all sidelobes

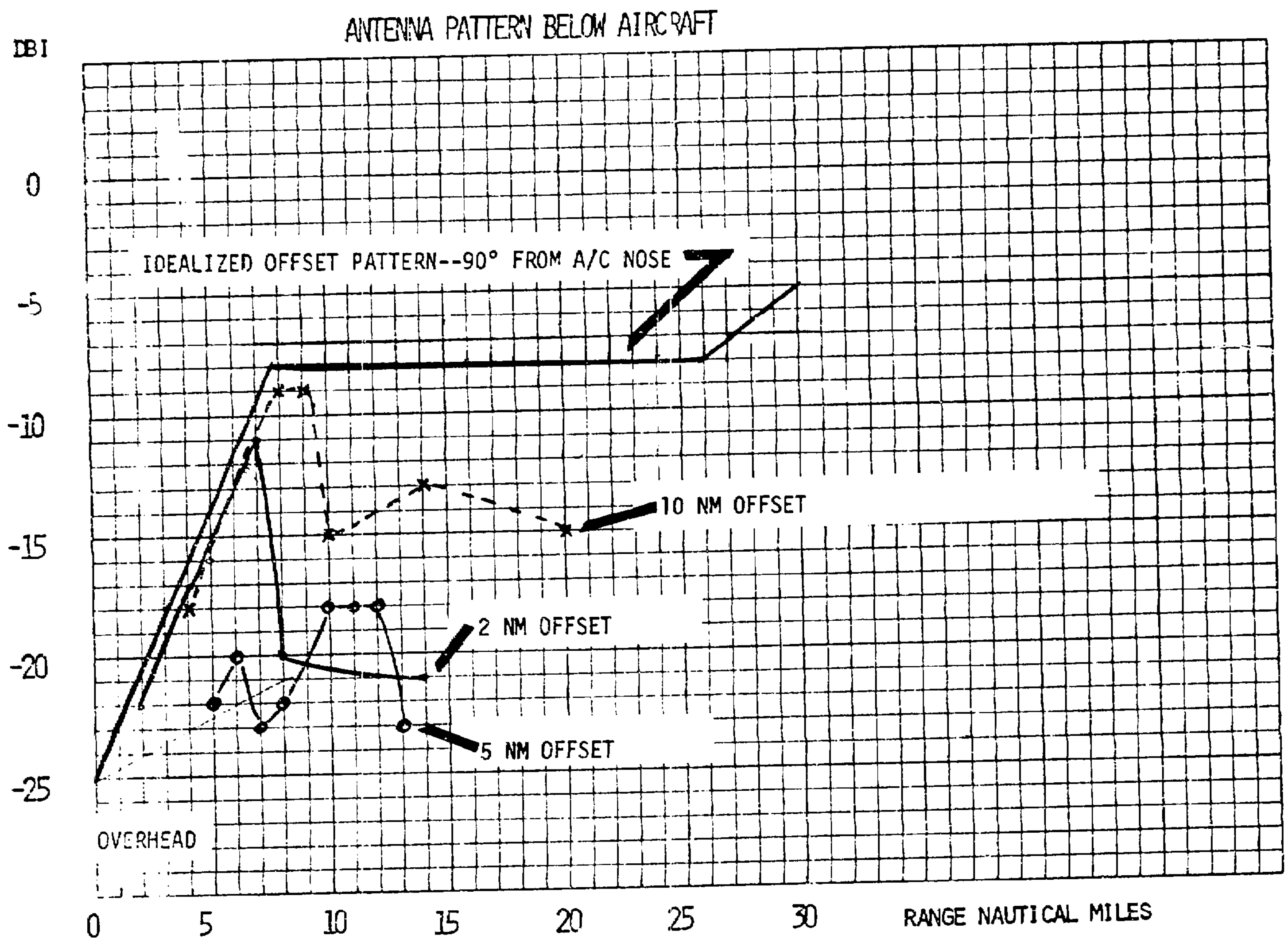


Figure A-7. Peak Signal Envelopes of Offset Passes

throughout a 360° of azimuth reduce to at least -25 dBi (RHCP). At other than 90° relative bearing the aircraft adds varying amounts of blockage to the sidelobe structure in the direction of the aircraft nose, tail and wings.

Major aircraft blockage began at 30 nautical miles for the "nose-on" case and about 8 to 10 nautical miles for the "off-the-side" case.

The absolute signal level received at the ground station remained relatively constant or dropped, even though the aircraft flew from 50 miles away to directly overhead. As shown in Table A-1, isolation increased (shielding) more rapidly than the distance effect dropped. Aircraft wings and tail provided large irregular shielding of -25 to -55 dBi during close-in flying.

At the beginning of the SHF Interference Study, an aircraft antenna gain of +1 to 0 dBi, based upon "aircraft-on-the-ground" measurements (Reference 15) was used to size the potential interference problem. The results of the "in-flight" aircraft antenna pattern test show that new aircraft antenna gain values should be used in any interference model. Figures A-8 and A-9 summarize the results of the antenna tests. Figure A-8 is the envelope of the peaks of the antenna gain curves for all relative bearings and all elevations. The antenna gain pattern is modeled as boresight, first sidelobe, and a series of three gain plateaus. In the boresight plane the main beam gain is 32 dBi (RHCP). The first sidelobe is 17 dBi (RHCP). From the first sidelobe to ±80° the sidelobe structure is about -1 dBi (RHCP). From ±80° to ±120° the sidelobe gain slopes to -8 dBi (RHCP). From ±120° to ±180° the sidelobe gain decreases

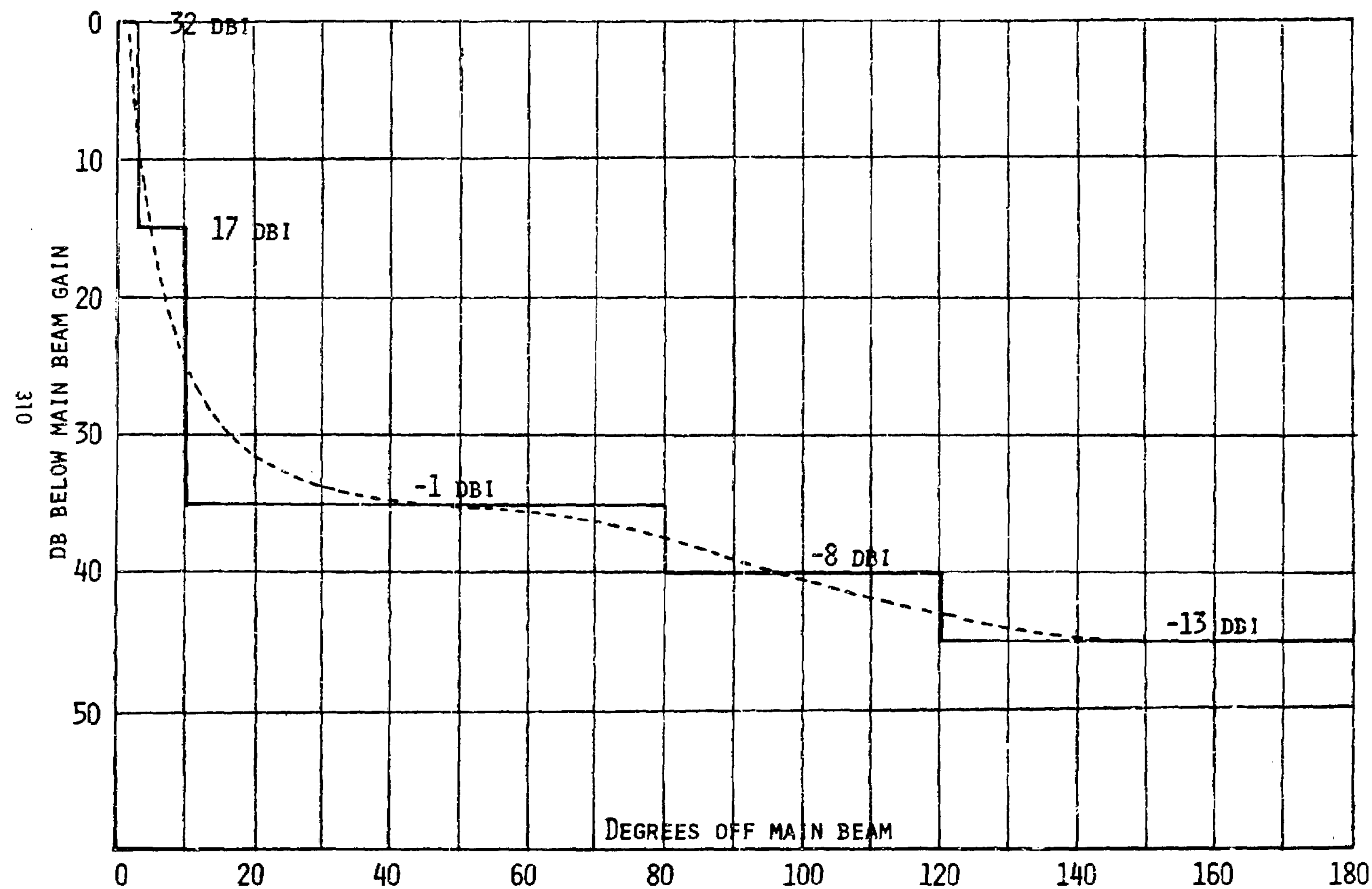


FIGURE A-8 AIRBORNE ANTENNA RADIATION PATTERN ENVELOPE

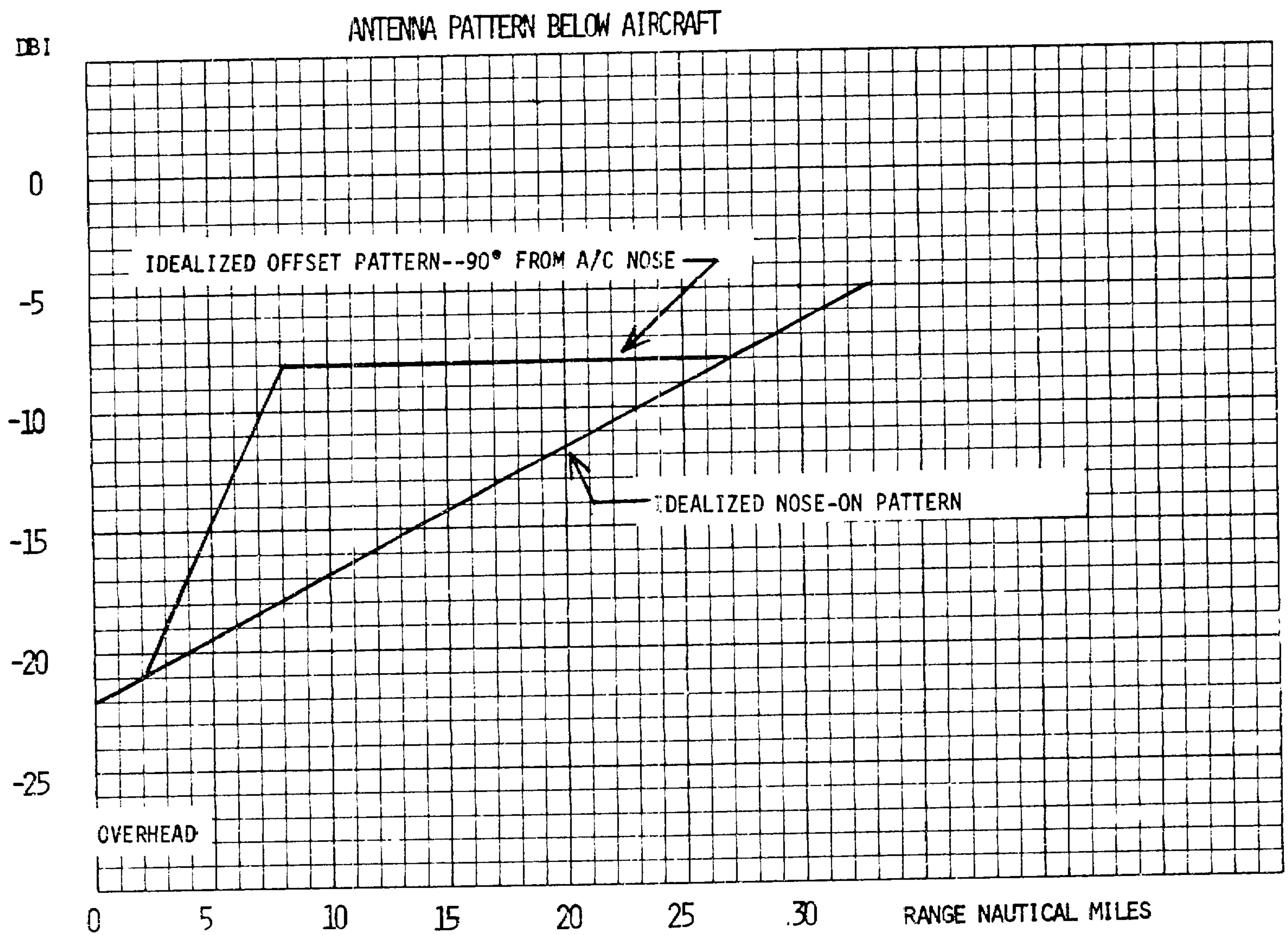


Figure A-9 Summary of Aircraft Shielding - Peak Envelopes of Nose-On and Offset Antenna Gain

to -13 dBi (RHCP).

For the close-in and overhead case, the aircraft antenna gain envelope of peaks is shown in Figure A-9. This is the worst case gain to be expected as the aircraft flies overhead or nearby a terrestrial microwave station.

APPENDIX B

BASELINE CHARACTERISTICS OF ASC-18 SHF SATCOM TERMINAL

GENERAL

The SHF SATCOM Set AN/ASC-18(V)(XA-1) consists of three groups.[32] These groups and the types of modulation available are described in this Appendix. Baseline operating characteristics are also presented.

COMMUNICATION TERMINAL GROUP, OW-72(V)(XA-1)/ASC-18

The Communication Terminal Group is composed of all the RF equipment in the AN/ASC-18 Satellite Communication Set with the exception of the antenna. The receiver equipment items are a pre-selector filter and low noise amplifier, two communications receivers, and a beacon receiver. The transmitter section consists of two exciters and a power amplifier. The group also contains a liquid heat exchanger with associated controls for cooling the power amplifier, an atomic frequency standard with an emergency battery power supply, and a test translator for direct input to output system testing. The operating characteristics of the terminal are given in Table B-1. The operation of the system is shown in the block diagram, Figure B-1, and is discussed briefly in the following paragraphs.

The transmitter accepts inputs of 70 or 700 MHz at 0 dBm and provides an output power up to 11 kW at the transmitter output throughout the 7.9 to 8.4 GHz frequency range. The signals from the two exciters are combined to provide simultaneous dual carrier transmission capability.

The power amplifier portion of the Transmitter Subsystem consists of a Traveling Wave Tube Intermediate Power Amplifier and a High Power Klystron Amplifier. The Klystron provides six preset 100 MHz channels selectable by a manual control on the tube.

TABLE B-1

COMMUNICATION TERMINAL GROUP CHARACTERISTICS

ITEM	CHARACTERISTICS	
GENERAL		
Low Level Cabinet		
Dimensions	60-1/2" H by 21" W by 25-1/2" D	
Weight	350 pounds	
Power Input Requirements	115 VAC, 380 to 420 Hz, 1750 W; +28 VDC, 425 W	
Power Amplifier Cabinet (without heat exchanger)		
Dimensions	60-1/2" H by 27" W by 25-1/2" D	
Weight	750 pounds	
Power Input Requirements	208 VAC, 3 phase, 4 wire, 380 to 420 Hz, 45 kW; +28 VDC, 250 W	
TRANSMITTER		
Frequency Range	7.9 to 8.4 GHz	
Power Level Range	Adjustable from 0.25 to 11.00 kW	
Exciter Inputs:		
Frequency	70 MHz	700 MHz
Level	0 ±1 dBm	0 ±1 dBm
Impedance	50 Ohms	50 Ohms
Bandwidth (1 dB)	40 MHz	100 MHz
Amplitude Response	2.0 dB p-p over any 100 MHz portion of the Transmit Band	
Phase Linearity	±0.5 Radian over the central 80 MHz of any Klystron Channel	
RF Channels	Continuously tunable in 10 Hz steps from 7.9 to 8.4 GHz	
Frequency Selection	Front Panel direct readout or Remote Digital Control	
Carrier Stability	2 parts in 10^{11} per month	

COMMUNICATION TERMINAL GROUP CHARACTERISTICS (Continued)

ITEM	CHARACTERISTICS		
COMMUNICATIONS RECEIVER			
Frequency Range	7.25 to 7.75 GHz		
Input Level Range	-140 to -70 dBm		
Noise Temperature	Less than 200°K		
IF Outputs:		Lo Level	Hi Level
Frequency	700 MHz	70 MHz	70 MHz
Impedance	50 Ohms	50 Ohms	50 Ohms
Level Range	-123 to -53 dBm	-123 to -53 dBm	-60 to +10 dBm
Bandwidth (1 dB)	100 MHz	40 MHz	40 MHz
Amplitude Response	1.5 dB p-p over the central 80 MHz of the Receiver passband		
Phase Linearity	$\pm$0.5 Radian over the 100 MHz passband of the Receiver		
RF Channels	Continuously tunable in 10 Hz steps from 7.25 to 7.75 GHz		
Frequency Selection	Front Panel direct readout or Remote Digital Control		
Carrier Stability	2 parts in 10^{11} per month		
BEACON RECEIVER			
Frequency Range	7.25 to 7.75 GHz		
Input Level Range	-140 to -110 dBm		
Modem/Tracking Receiver Outputs:			
Frequency	0.5 MHz		
Impedance	50 Ohms		
Level Range	-70 to -40 dBm		
Bandwidth (3 dB)	120 kHz		
Amplitude Response	0.5 dB p-p over the central 20 kHz		
Doppler-Corrected Outputs:			
Nominal Frequency	5 MHz		
Correction Sense	Plus and minus doppler		
Impedance	50 Ohms		
Level	0.5 VRMS		

COMMUNICATION TERMINAL GROUP CHARACTERISTICS (Continued)

ITEM	CHARACTERISTICS
BEACON RECEIVER (Continued)	
IF Outputs:	
Frequency	70 MHz
Impedance	50 Ohms
Level Range	-123 to -53 dBm when used as a Communication Receiver
Bandwidth	40 MHz
Amplitude Response	3 dB p-p over 40 MHz of bandwidth
Lock and Capture Range	± 10 kHz of doppler shift
RF Channels	Tunable in 10 kHz steps from 7.25 to 7.75 GHz
Frequency Selection	Front Panel direct readout or Remote Digital Control
Carrier Stability	2 parts in 10^{11} per month
TEST TRANSLATOR	
RF Input	7.9 to 8.4 GHz
Level	+10 to +30 dBm
Impedance	50 Ohms
RF Output	7.25 to 7.75 GHz
Level	-40 dBm or -80 dBm, switch selectable
Impedance	50 Ohms
Translation Frequency	720 MHz, phase-locked to frequency standard
Amplitude Response	± 0.25 dB over any 100 MHz
Phase Linearity	± 0.1 Radian over any 100 MHz segment
FREQUENCY STANDARD	
Output:	
Frequency	100 kHz, 1 MHz, 5 MHz sinusoidal and 100 kHz clock drive

COMMUNICATION TERMINAL GROUP CHARACTERISTICS (Continued)

ITEM	CHARACTERISTICS	
FREQUENCY STANDARD (Continued)		
Stability	Long Term: less than $\pm 2 \times 10^{-11}$ per month	
	Deviation	Avg Time
	Less than 7×10^{-12}	1 sec
	Less than 2.2×10^{-12}	10 sec
	Less than 7×10^{-13}	100 sec
Levels	1 VRMS into 50 Ohms: clock drive 0.5 VRMS into 1000 Ohms	

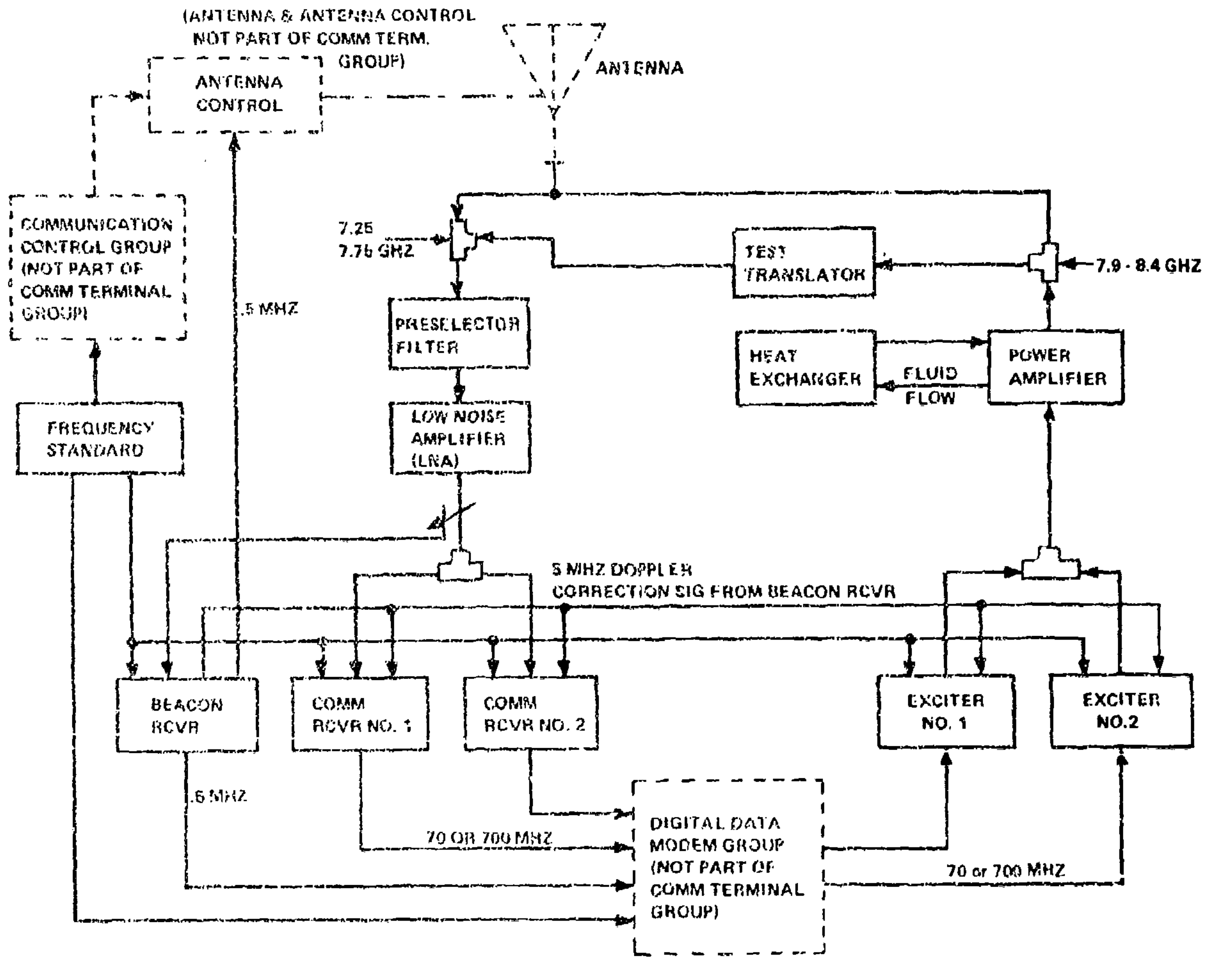


Figure B-1. SHF Communications Terminal Group, Block Diagram

The exciter frequency is determined by an Integral Frequency Synthesizer that is continuously tunable in 10 Hz steps over the range of 7.9 to 8.4 GHz. The synthesizer frequency reference is derived from a Rubidium Atomic Frequency Standard. A frequency reference signal with doppler correction is provided by the Beacon Receiver.

The Receiver Subsystem contains a pre-selector filter, a low-noise parametric amplifier, and two communications receivers that operate from 7.25 to 7.75 GHz. Outputs from the receivers are at 70 MHz and 700 MHz, and the levels are compatible with satellite communication modems. Instantaneous 1 dB bandwidth for the Receiver Subsystem is 100 MHz at the 700 MHz output terminal, and 40 MHz at the 70 MHz output terminal. Each receiver has an Integral Frequency Synthesizer identical to the one in the exciter that is continuously tunable in 10 Hz steps over its operating range.

The Beacon Receiver Subsystem receives Beacon signals from the satellite and converts these signals to a 70 MHz IF, a 0.5 MHz modem and a 0.5 MHz tracking receiver output. The Beacon Receiver contains an Integral Frequency Synthesizer that is continuously tunable in 10 KHz steps over the 7.2 to 7.75 GHz range. The Beacon Receiver also supplies doppler corrected 5 MHz reference signals to the receiver and transmitter that may be used in place of the Atomic Frequency Standard.

The Test Translator is used to check the terminal in a back-to-back mode. It accepts a sample of the signal from the transmitter and translates it down by 720 MHz into the receive band. The sample is then applied to the receivers. The DSCS II satellite frequency translation, however, is 725 MHz for channels 1, 2 and 3 thus allowing the translator to perform

on-line checking of the terminal without interference with the satellite signal. This on-line check is in addition to normal RF back-to-back terminal maintenance and confidence checks. It should be noted that on-line translator operation during a mission which utilizes satellite cross channel 4 will not be possible due to this channel's lower translation frequency.

The Heat Exchanger Pump and Control Unit provides the fluid, power, regulation and control for the liquid cooling circuits in the SHF Power Amplifier. The air flow through the system results from either ram air or blown air. The ram air is for operation during flight and is supplied from side mounted air scoops. The blown air mode is used during terminal operation while on the ground and is supplied from the built-in blower system.

ANTENNA CONTROL GROUP, OE-150(XA-1)/ASC-18

The SHF Airborne Antenna Control Group consists of a lightweight, high power, high gain, narrow beam antenna designed specifically for communications from an aircraft to a synchronous satellite. On board electronics are used to stabilize the antenna and keep it pointing at the satellite. The antenna is located within a low loss radome on the top midsection of the test aircraft. A block diagram of the Antenna Control Group is shown in Figure B-2. This system's characteristics are listed in Table B-2 and briefly discussed in the following paragraphs.

The antenna is a Casseyrain System composed of a 33-inch Parabolic Main Reflector and a six inch Hyperbolic Sub-Reflector. The system has a power handling capability of 12.5 kW without liquid or forced air cooling. This power handling capability was achieved by improving the thermal design of an existing airborne antenna system for better conduction, convection, and radiation cooling and by improving the RF efficiency to reduce the heat input.

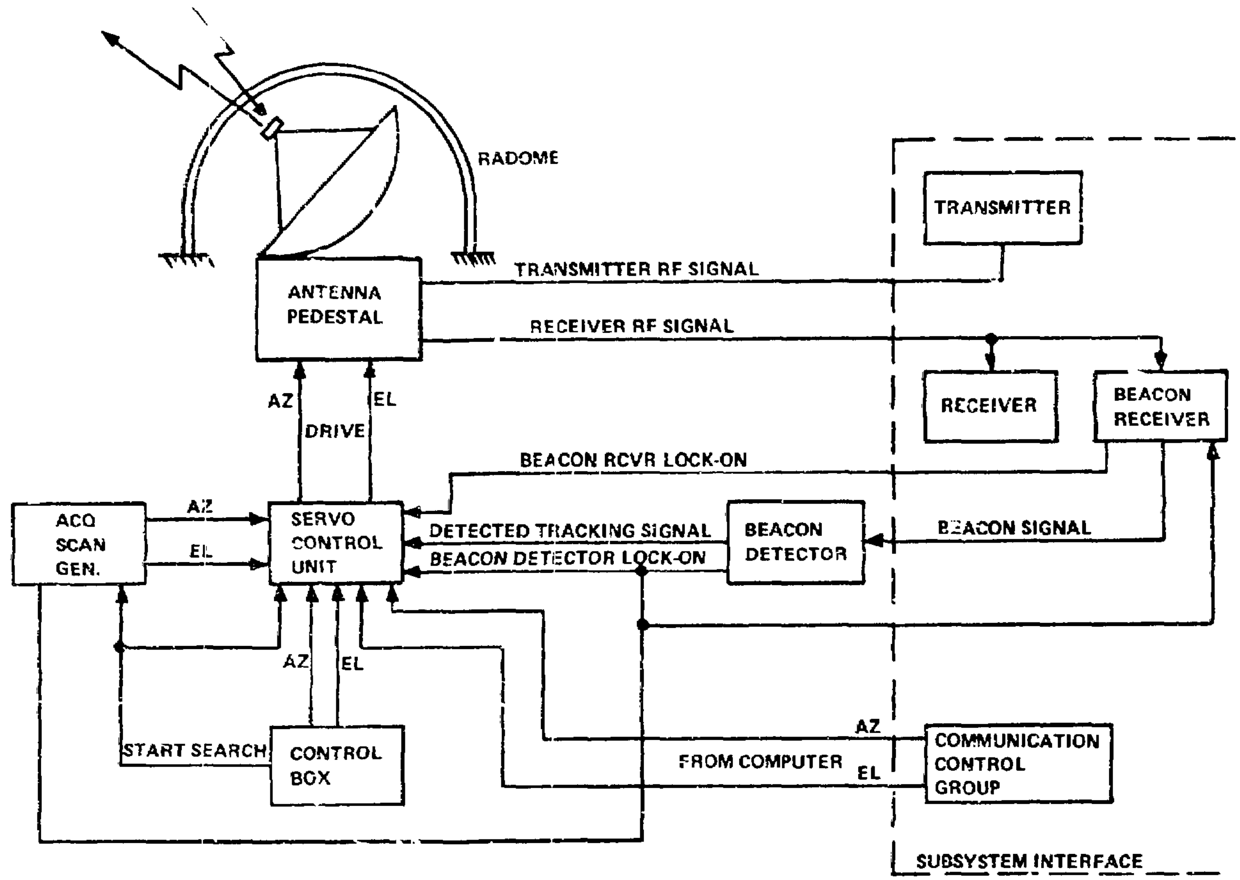


Figure B-2 Antenna Control Group Block Diagram

TABLE B-2

ANTENNA CONTROL GROUP CHARACTERISTICS

ITEM	CHARACTERISTICS
ANTENNA	
Frequency	7.25 - 8.4 GHz
Gain	33.2 dB at Tx, 34.3 dB at Rx
Polarization	Xmit RHCP, Rcv LHCP
Axial Ratio	1.0 dB
Beam Shape	Symmetrical
Sidelobes	-14 dB
VSWR	1.35
Losses	0.5 dB
Power Handling	12.5 kW CW
Isolation	20 dB
Antenna Noise Temperature	Less than 92°K (calculated from measured data at 83.6°K)
PEDESTAL	
Mode of Operation:	
Manual	Two-speed 360 degree azimuth and -5 to +88 degree elevation positioning. Zero azimuth and elevation referenced to direction of flight.
Computer	360 degree azimuth and -5 to +88 degree elevation positioning as commanded from Computer D/A Converter.
Search/Track	Automatic raster scan search at 8°/sec maximum over a 20 x 20 degree window. A target (Satellite Beacon) signal of 34 dB (nominal) carrier-to-noise ratio in a 1 Hz bandwidth (C/N_o) initiates 0.5 x 0.5 degree track scan.
Tracking Scan Frequency (nominal)	1 Hz Elevation 0.5 Hz Azimuth

ANTENNA CONTROL GROUP CHARACTERISTICS (Continued)

ITEM	CHARACTERISTICS
Radiation Hazard Cut-Off	Limited Profile
Subsystem Weight	Approximately 300 pounds (plus nitrogen unit)
Antenna	
Portion below mounting plane (aircraft interior)	13 inches maximum diameter
	16 inches maximum length, excluding Electrical, Microwave and Nitrogen System interface connections

The antenna is housed in a radome located on the top midsection of the test aircraft's fuselage. The radome has very low loss characteristics for a structure with the rigidity required to resist deformation from the wind load stresses encountered. This low loss characteristic was accomplished by the use of a low density (honeycomb) dielectric material, bonded between thin, high density inner and outer skins. The signal attenuation at transmit frequencies is zero and about 1 dB at receive frequencies. This receive attenuation holds for all antenna bearings except when pointed toward the tail (azimuth 180 degrees) at near zero elevation angles where the attenuation increases 3 to 4 dB.

The antenna is mounted on an elevation over azimuth pedestal designed for continuous sky coverage from below horizon to nearly vertical with each axis being positioned by the use of direct drive DC torque motors.

Antenna pointing is accomplished by one of the following methods:

Manual Mode - The antenna is pointed by the operator through the use of azimuth and elevation slew switches which provide direct rate inputs to each axis of the pedestal's servo system. When "at rest" in this mode, the system is space stabilized by two rate gyros mounted on the back of the main reflector.

Computer Mode - The antenna is pointed by commands from the Communications Control Group (not part of the Antenna Control Group). This computer provides continuously updated pointing signals to the antenna pedestal's servo system based on inputs derived from the aircraft's navigation system and satellite ephemeris data.

Active Track Mode - The antenna continuously points at a satellite by locking on to the satellite beacon signal. The sequence of events to accomplish lock-on initially requires the antenna to be manually positioned as closely as possible. A spatial acquisition mode is then activated which provides an automatic raster scan of ± 10 degrees to aid in locating the satellite beacon. When energy is detected, the raster scan is inhibited, and a frequency search is initiated to phase lock the

system to this beacon signal. The system finally assumes an automatic bow-tie scan mode to maintain correct antenna pointing. This bow-tie scan resolves azimuth and elevation error by applying the error signals to the appropriate axis drive for corrective positioning.

COMMUNICATIONS CONTROL GROUP, OK-227(XA-1)/ASC-18

The OK-227 Communications Control Group incorporates a computer capability into the Antenna Tracking System to provide the communications set with added flexibility and operational capabilities. Acquisition of the satellites is significantly reduced in complexity and time by computer designation of the antenna pointing angles to the satellite based on aircraft location and orientation data, and satellite ephemeris data. The computer may also be used to supply doppler and range information to the terminal.

The computer capability permits operation with "silent" satellites and allows quick reacquisition with "active" beacon satellites in the event of loss of a beacon signal. In addition, computer aided acquisition and tracking becomes invaluable if a number of satellites are to be sequentially used to maintain communications. The handover operation, which normally required several minutes of coordinated effort by the operator and pilot, is accomplished in a few seconds by computer substitution of new satellite ephemeris data without requiring special operations or calculations by the operator or pilot. The computer-augmented system also permits the tracking of non-synchronous satellites where the satellite position (relative to the aircraft) rapidly changes, preventing the use of conventional manual designation, beacon signal acquisition and tracking techniques.

The Communications Control Group consists basically of a small computer with the required I/O devices and other miscellaneous peripheral equipment. A list of the equipment items (including some not technically within this system but closely associated with it) is given in Table B-3. A basic block diagram indicating the interrelationship as shown in Figure B-3, and a brief discussion of several of the more pertinent characteristics is given in the following paragraphs.

The Computer Pointing System (CPS) Control Panel, as illustrated by Figure B-4, provides selection of any one of three operating modes. The Computer Designate and Track Mode (CMPTR DES/TRK) operates the antenna in a "non-active track" configuration and can be used with silent satellites. A second mode (MAN DES ACTIVE TRK) is provided for use with active beacons and allows the antenna to operate without the computer by using the conventional raster search pattern, manual designate and active track processes. The third mode (CMPTR DES ACTIVE TRK) is a mixture of the previous two with computer designation of the target, followed by active beacon tracking. The difference between the true tracking angle (active track) and the computer tracking angle is indicated as degrees of traverse and elevation error by the two meters mounted on the panel. Other panel controls are provided for selection of the ephemeris data to be used from the four sets of data stored in computer memory, for the display of system condition and for the selection of a computer self-test mode.

The computer unit utilizes the data inputs from the other associated units to automatically designate the SHF antenna to within the prescribed limits of the selected satellite position. This is accomplished by computing instantaneous pointing angles to the satellite relative to the

TABLE B-3

COMMUNICATION CONTROL GROUP CHARACTERISTICS

ITEM	CHARACTERISTICS
INPUTS	
Fine Altitude	Synchro from CPU-66/A-I
Azimuth	Synchro from INS
Pitch	Synchro from INS
Roll	Synchro from INS
Latitude	Serial digital from INS
Longitude	Serial digital from INS
Ground Speed	Serial digital from INS
Wander Angle	Serial digital from INS
Time of Day	Serial digital IRIG-B
Antenna Azimuth	Synchro from Antenna Control System
Antenna Elevation	Synchro from Antenna Control System
Program	High speed tape reader
OUTPUTS	
Antenna Azimuth Commands	Analog
Antenna Elevation Commands	Analog
Satellite Range	Analog and digital
Satellite Doppler Correction Signal	Analog and digital
INPUT/OUTPUT	
Satellite Ephemeris Data, Course	Teletype and Tape
Altitude, Diagnostic Data	Reader/Punch
Accuracy at end of 12 Hour Operation*	
Antenna Pointing Accuracy**	$\pm 1.5°$
Doppler Output Accuracy	± 300 Hz
Range Output Accuracy	± 1000 meters

*Based on INS (LTN-51) 3σ positional error 6.75 arc minutes per hour of flighttime.

**To be met under the following conditions:

Pitch Rate	10 deg/sec
Pitch Acceleration	10 deg/sec/sec
Roll Rate	10 deg/sec
Roll Acceleration	5 deg/sec/sec
Yaw Rate	4 deg/sec
Yaw Acceleration	4 deg/sec/sec

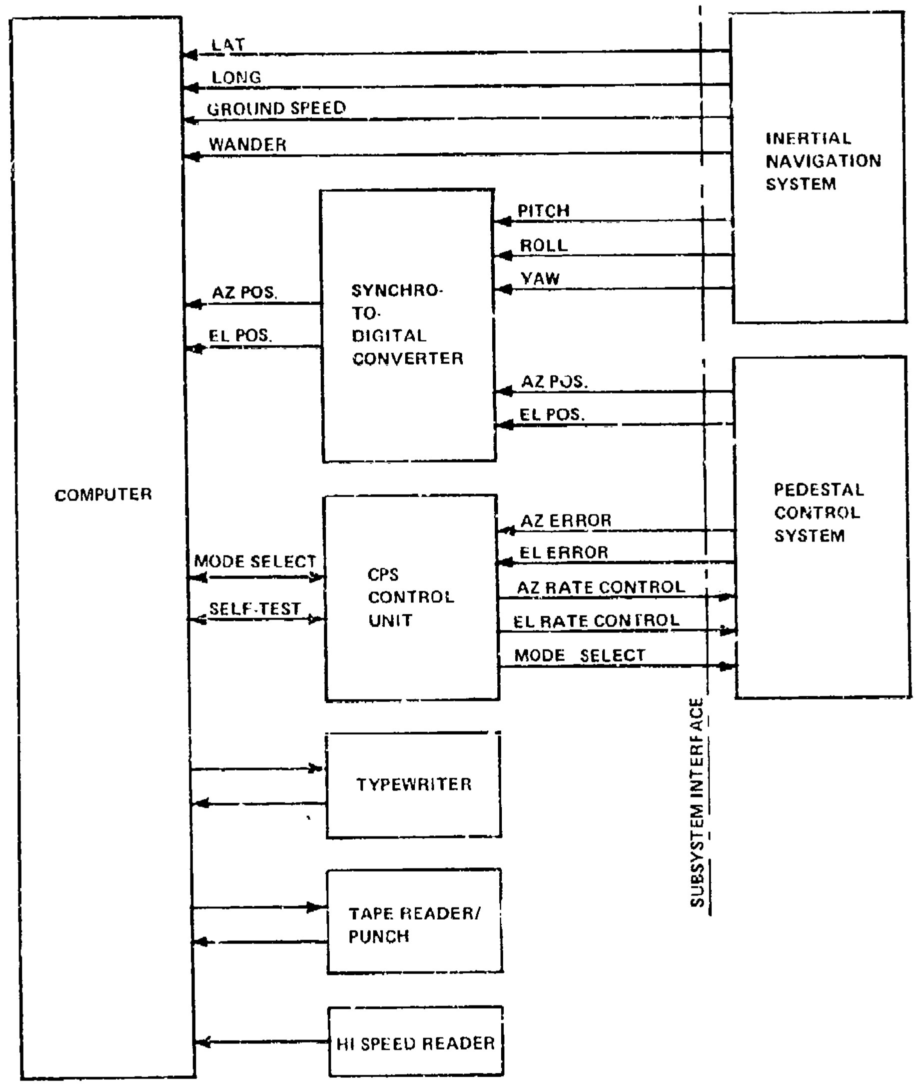


Figure B-3 Communications Control System Block Diagram

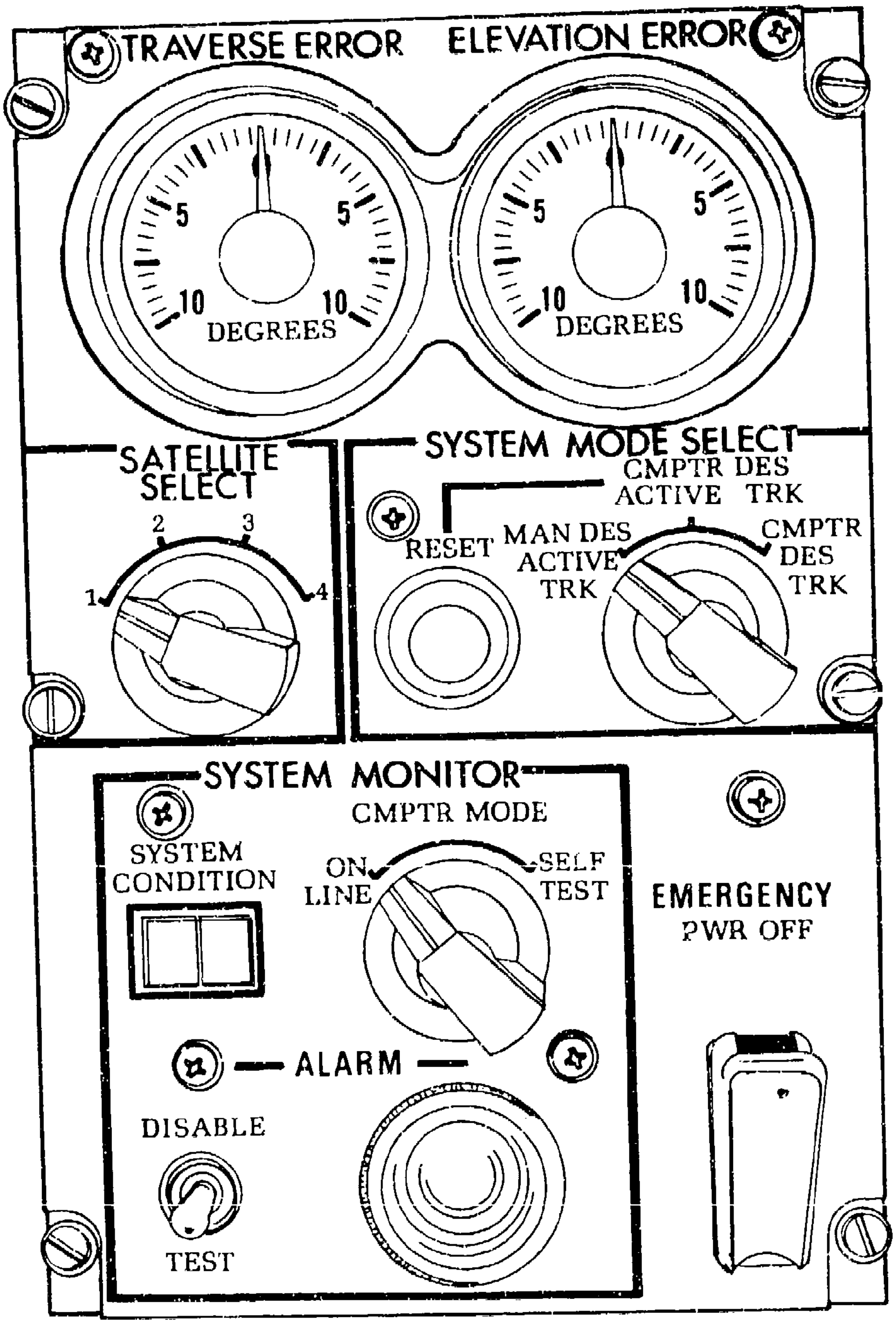


Figure B-4 Communications Control Group, Control Panel

antenna pedestal. These angles are a function of three separate conditions: satellite position, aircraft position and aircraft attitude. The following is a brief summary of the computations performed to determine these angles. The satellite and aircraft positions are converted to the same system of coordinates (geocentric). Corrections are inserted for aircraft attitude to provide a stable reference platform. When all variables have been compensated, the satellite coordinates relative to the airframe are determined, and the antenna pointing angles are computed.

The computer interface unit consists of registers, buffers, decoders and timing and control logic to handle the flow of data into and out of the computer. A front panel on the interface unit contains indicator lamps and switches used for monitoring certain system parameters. Additional monitoring indicators are located on the CPS control panel.

The teletypewriter set is used primarily to insert up to four sets of satellite ephemeris data into the computer memory via the interface unit. It punches a paper tape which then supplies the data to the computer at a relatively low speed. The teletypewriter is also used as a fault isolation and monitoring tool.

The synchro-to-digital converter receives azimuth and elevation position signals from the synchros on the antenna pedestal of the SHF antenna subsystem, attitude data from the aircraft's air data computer, and some of the INS inputs. It converts these analog signals to digital form and supplies the digital data, via the interface unit, to the computer for real-time use.

The inertial navigation system (not part of the Communications Control Group) is the prime source of aircraft flight motion data. Longitude,

latitude, velocity, pitch, roll and heading data are fed into the computer, via the interface unit, in real-time.

MODULATIONS AVAILABLE

The ASC-18 transmitter can accept a variety of modulations. Four types were used for interference testing. These were:

(1) Pseudo-noise Phase Shift Keyed modulation from the USC-28 Modem.

(2) A frequency-hopping Multiple Frequency Shift Keying modulation from the Wideband Anti-Jam Modem, ASC-18(OM-42).

(3) A narrowband frequency modulation from a Collins Radio FM Modem (965-R1).

(4) An unmodulated carrier (CW) from any of several sources.

USC-28 The AN/USC-28 PN Modem utilizes the band spreading nature of a high rate 40 megabit direct sequence pseudo-random noise to phase modulate a carrier. Combined within this are two link order wires, a data user and an address code for the specific user selected. The spectrum[33] is a $(\sin x/x)^2$ and is limited only by the bandpass of the transmitter.[34] This modulation was the primary test modulation.

AN/ASC-18(OM-42) Wideband Anti-Jam Modem - The modem's signal structure uses Reed-Solomon encoding with signaling by Multiple Frequency Shift Keying. The band spreading results from frequency hopping the carrier according to a selected code and address. This code may be a fixed or a pseudo-random code. Only the pseudo-random code hopping was used for the interference test. Since the hopping rate is only a little faster than the user data rate (19.2 Kbps maximum), the sidebands outside of the actual hopping bandwidth are relatively small.

Narrowband Frequency Modulation - The Collins FM Modulator-Demodulator (965-R1) has twelve half-duplex FM channels, one of which may be used at a time. These channels span plus or minus 250 kHz from the center frequency of 70 MHz. Deviation is 10 kHz peak-to-peak for audio voice from 300 to 3000 Hz. This FM voice channel was used as an order wire during testing.

Continuous Wave Modulation (CW) - The ASC-18 transmitter produced a SHF CW carrier when fed with a CW IF signal at either 700 MHz or 70 MHz. The IF CW source was one of the above modems in a CW mode or an appropriate frequency generator. All CW signals were of sufficient purity that residual modulation was not of concern.

APPENDIX C

ATTIC ANALYSIS PROGRAM

With the installation of any microwave communication system, a primary consideration must be to establish an operating environment which will create no more than a maximum permissible level of interference with co-channel users. Methods of establishing and maintaining such an environment for proposed or planned <u>fixed</u> terrestrial stations have been devised and are in accepted practice. However, until now, such procedures have not been implemented with proposed or planned airborne communication systems. Implementation of such procedures has previously excluded airborne communication systems because of the tremendous amount of analysis required of a system whose parameters vary in time and space. With the design and contruction of the computer program (ATTIC)*, the frequency manager or spectrum analyst now has access to a powerful tool which allows one to include both airborne and <u>fixed</u> terrestrial systems in analyzing an operational environment. Specifically, ATTIC has the ability to automatically compute and plot coordination areas around existing microwave systems when new airborne systems are proposed or planned.

A family of signal-to-interference ratio (S/I) contours plotted on a map with state boundaries is the primary output produced by ATTIC. The interference (I) is from a transmitter on an aircraft which flies near terrestrial microwave receivers; the signal (S) is the median received signal at each terrestrial receiver from its associated transmitter. The map represents the area over which the aircraft is allowed to fly with its transmitter in operation.

*Airborne Terminal to Terrestrial Terminal Interference Calculations

Figure C-1 illustrates the interference situation which ATTIC models. A general flow chart for this process is illustrated in Figure C-2. Assuming that the desired received signal of the terrestrial station does not change (as a result of fades, etc.) as the aircraft flies around the receiver, then the computed S/I values will depend on the aircraft geometry with respect to the receiver, the aircraft's antenna gain in the direction of the ground receiver (all other system variables are held constant). One would expect as the aircraft flies closer to the receiver, the received interference power will increase. Also, as the main beams of the aircraft antenna and the terrestrial receive antenna become more closely aligned, the received interference power will increase.

Every S/I contour map and its associated output comprises four distinct sections each of which is plotted on separate microfilm frames. The four sections are:

(1) Input and control information used during the interference analysis.

(2) The resultant S/I contour map.

(3) S/I area statistics from the S/I contour map.

(4) Tabulated parameters of those receivers for which S/I calculations were made.

Each S/I contour map can be plotted for one or a number of user supplied values. Figure C-3 illustrates a typical composite S/I contour plot for a range of values that extend from 26 to 36 dB S/I in 2 dB intervals. A single contour for 28 dB S/I is illustrated in Figure C-4. It snould be noted that S/I "contour islands" of the same level occur at

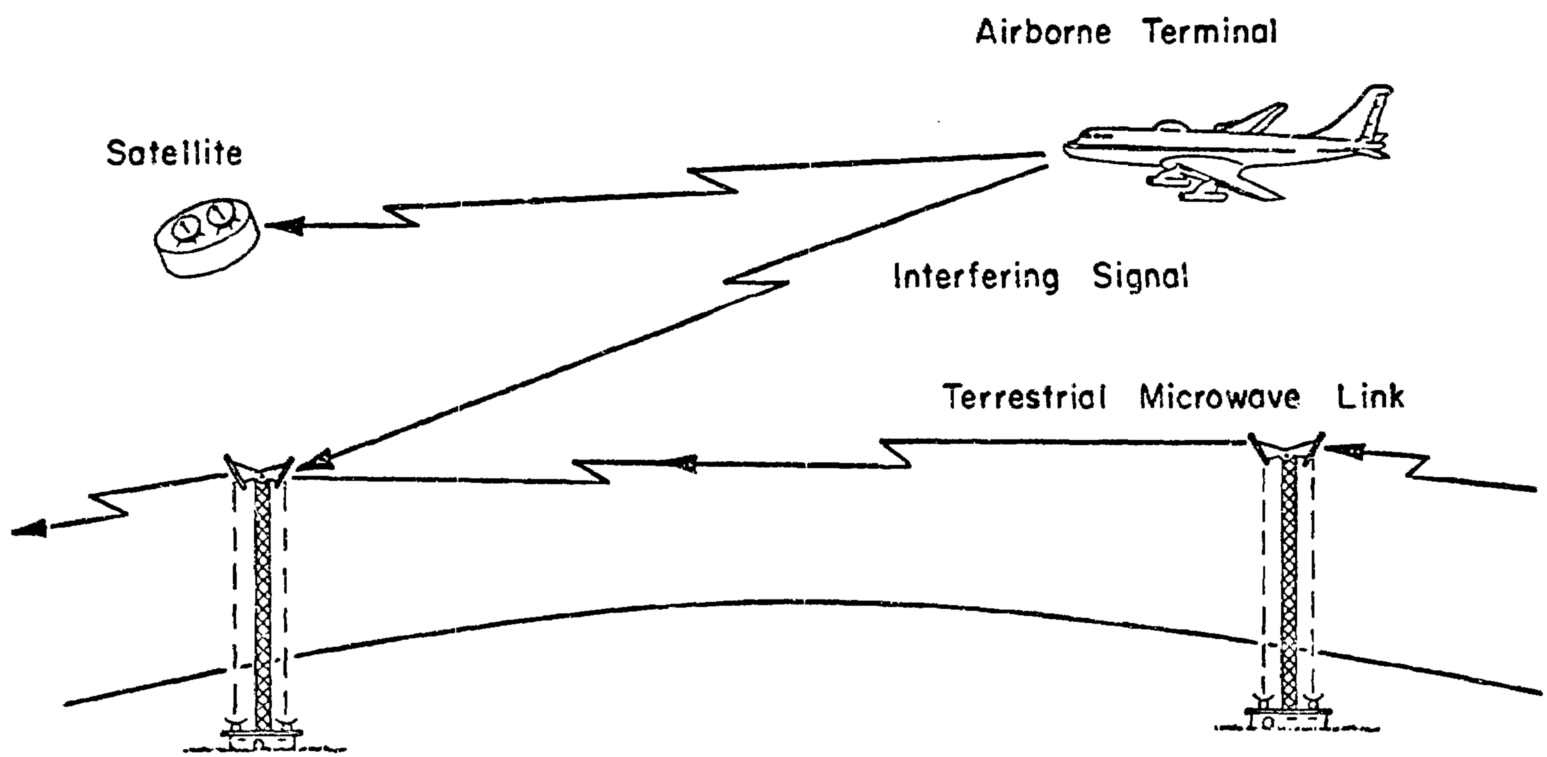


Figure C-1. Interference to Microwave Link from Airborne Satellite Terminal

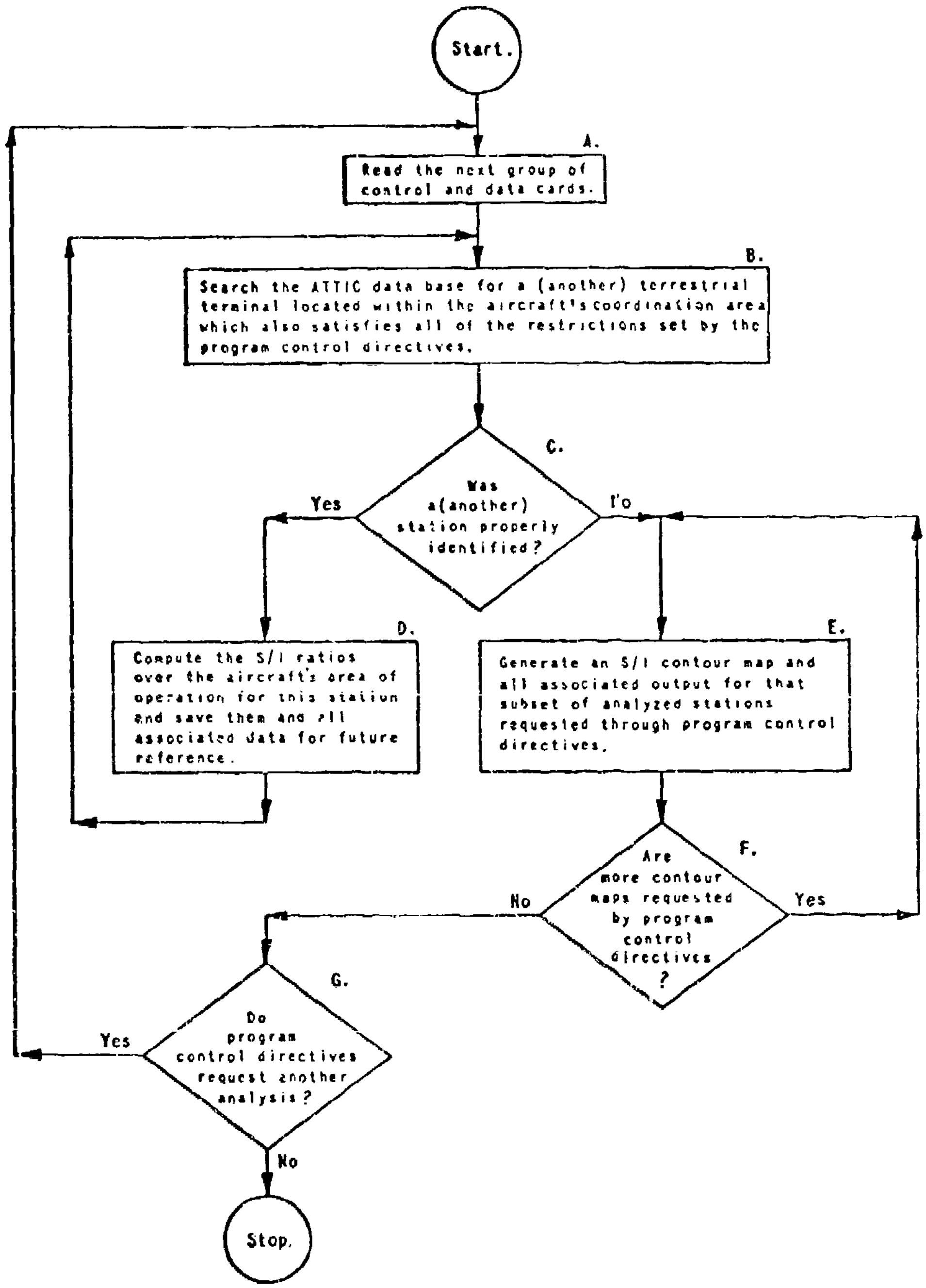


Figure C-2. ATTIC Program Flowchart

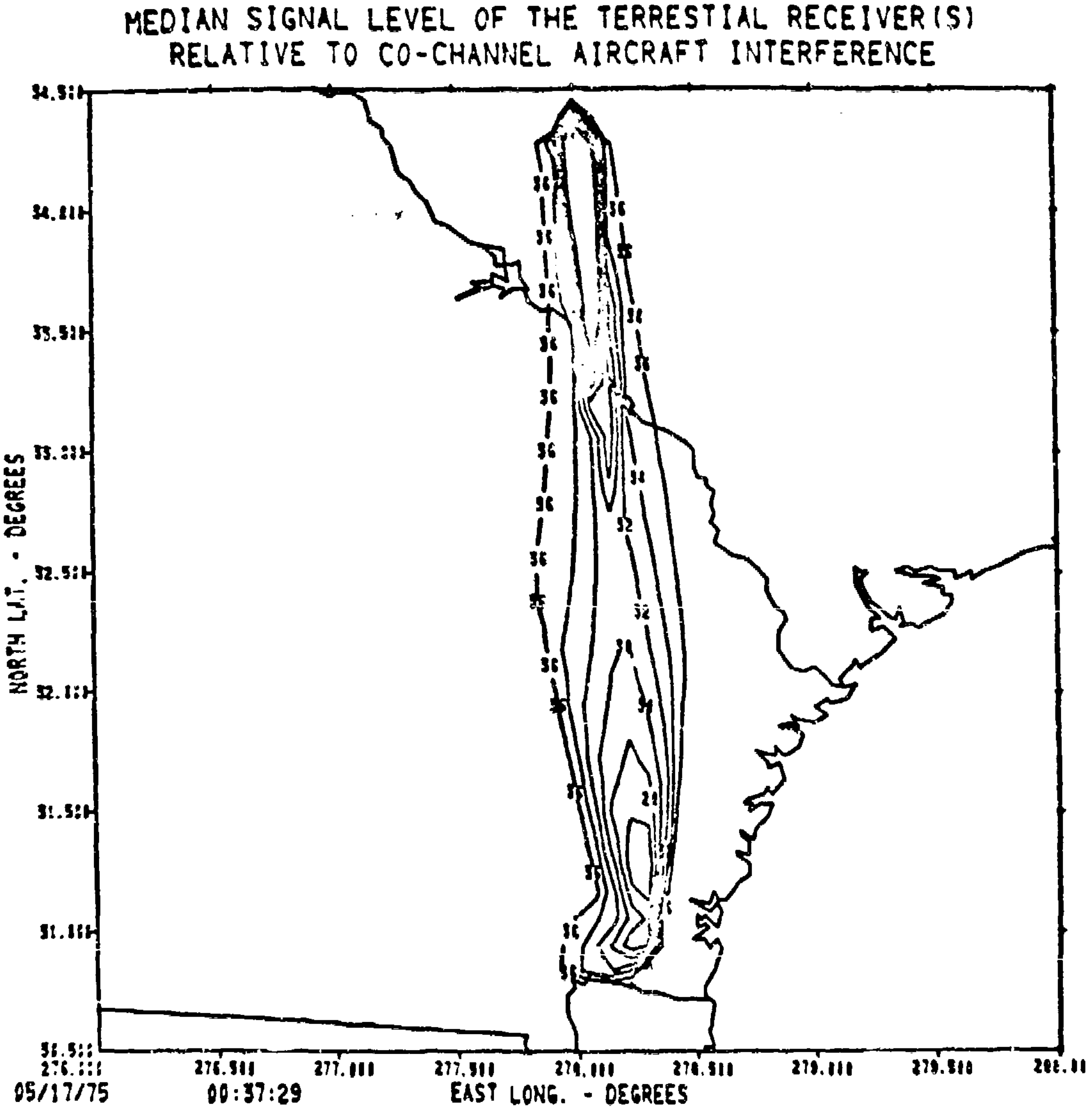


Figure C-3. Composite S/I Contours

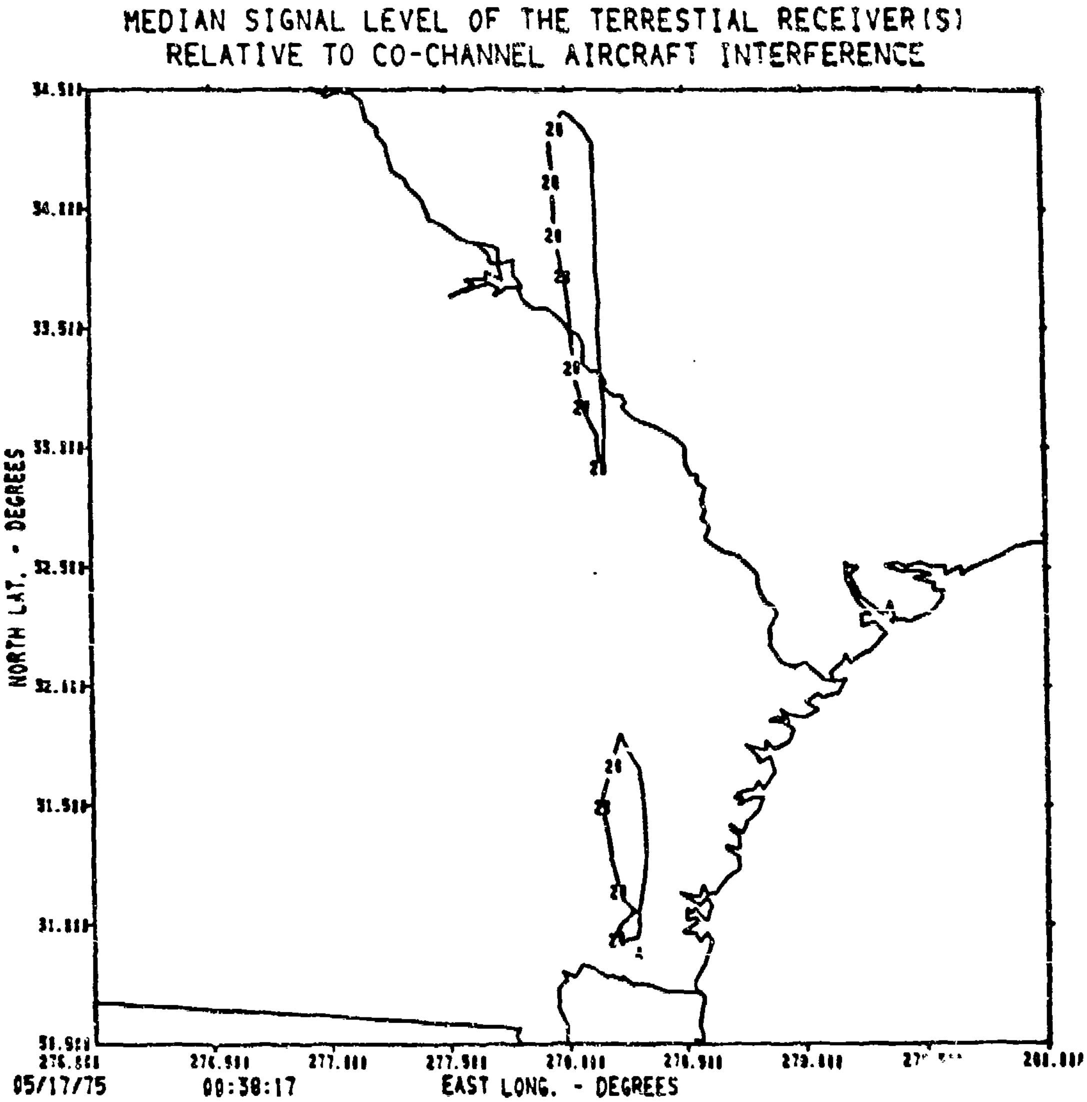


Figure C-4. Single S/I Contour

two widely separated distances along the main beam path of the terrestrial receiver. The analysis may be tempted to perceive these discrete islands as one large "contour island." However, this would be a misconception as to the actual S/I levels encountered. Though not intuitively obvious, this "contour island" formation is merely caused by interaction of basic transmission loss in conjunction with path antenna gain. The "contour islands" furthest from the terrestrial receiver (the aircraft appears close to the terrestrial receiver's horizon and main beam path) correspond to high coupling through antenna patterns. At this distance the basic transmission loss varies quite slowly with change in slant range. As the aircraft starts to approach the terrestrial receiver along its main beam path, path antenna gain coupling drops dramatically with small angle changes from the antenna main beam while the basic transmission loss decreases only slightly. However, upon further approach to the terrestrial receiver, the path antenna gain becomes fairly constant but the basic transmission loss drops rapidly. Interference is high when the aircraft appears on the terrestrial receiver's horizon because it passes through the receiver's main antenna beam. Interference is again high when the aircraft is close to the terrestrial receiver only because of a large decrease in basic transmission loss. Therefore tne "contour islands" are correct as they stand.

Figure C-3 and C-4 only consider a single microwave receiver. The program will also consider multiple receivers in the environment and can provide either a composite plot of all S/I values (see .gure C-5) as well as a single value.

MEDIAN SIGNAL LEVEL OF THE TERRESTIAL RECEIVER(S)
RELATIVE TO CO-CHANNEL AIRCRAFT INTERFERENCE

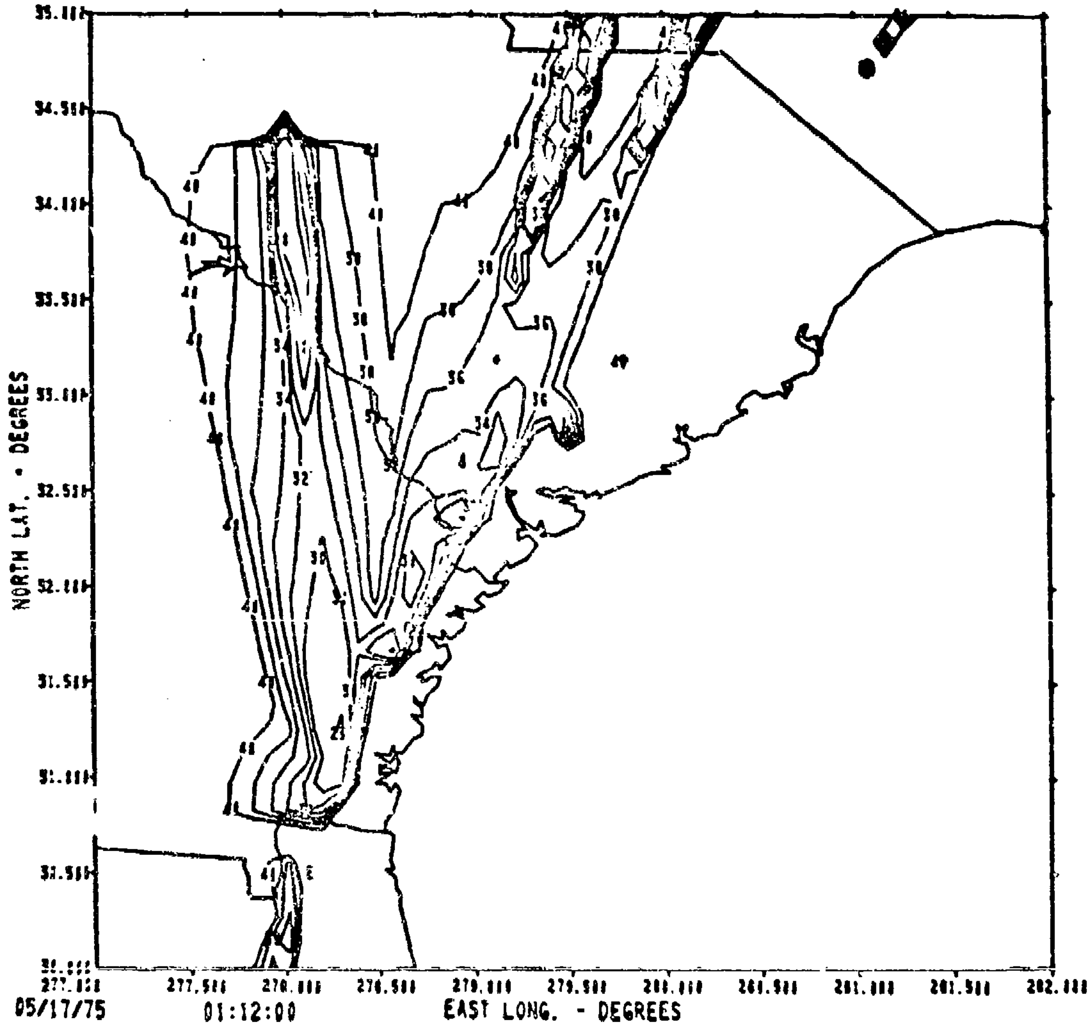


Figure C-5. Composite Contours for Four Microwave Receivers

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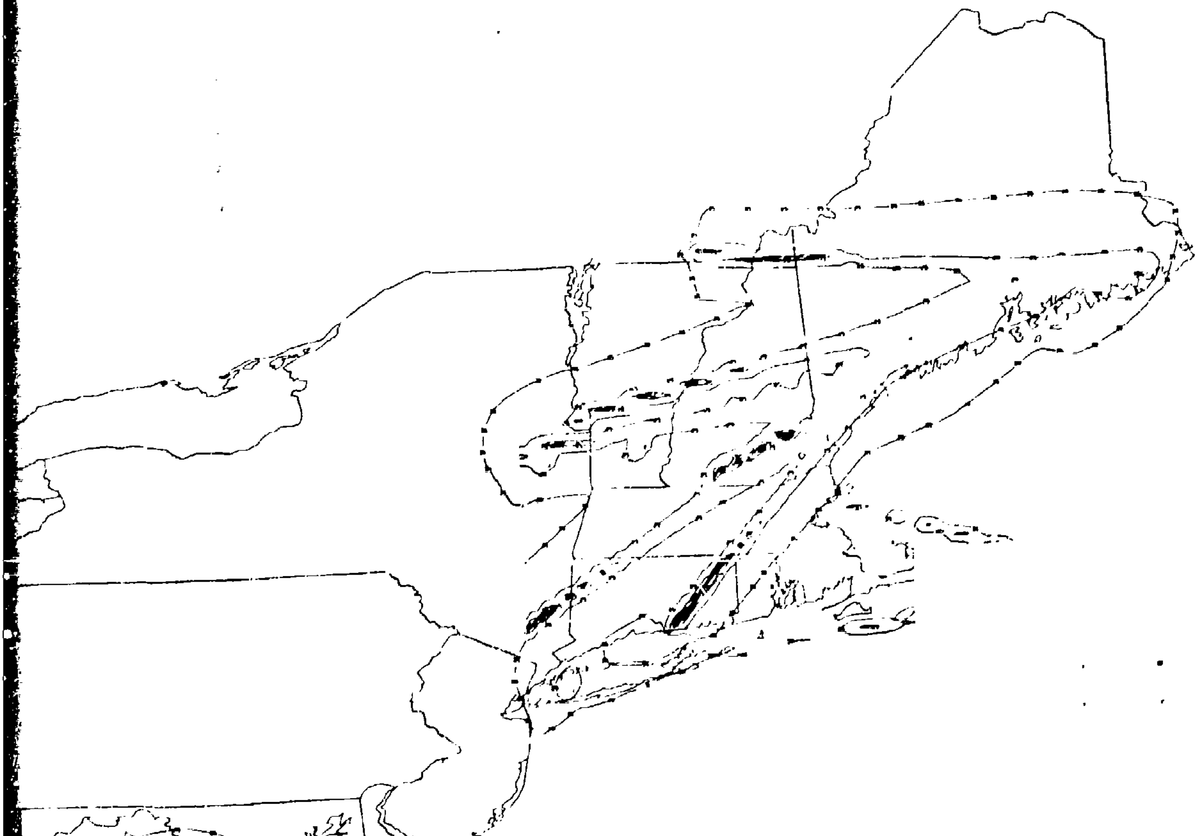

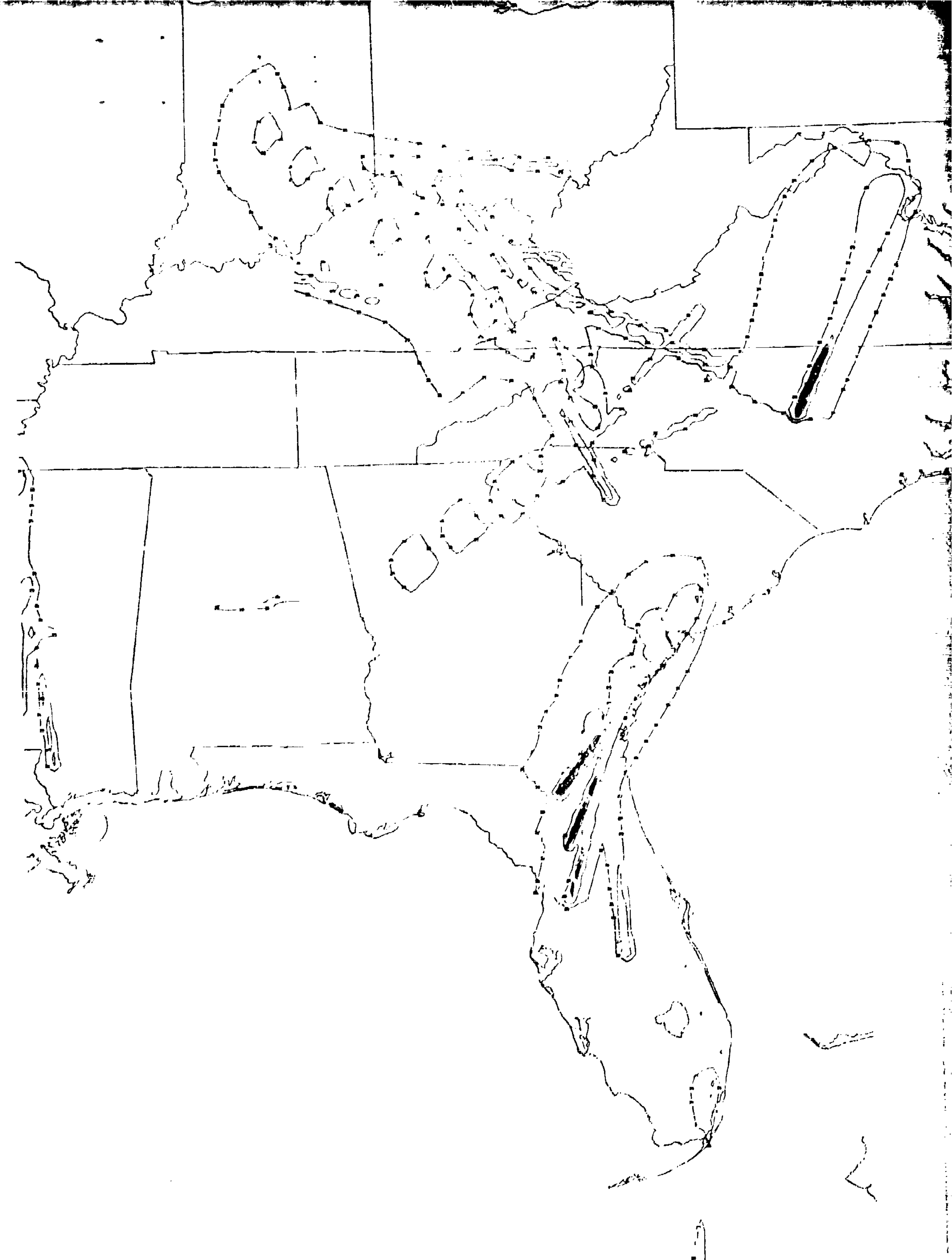

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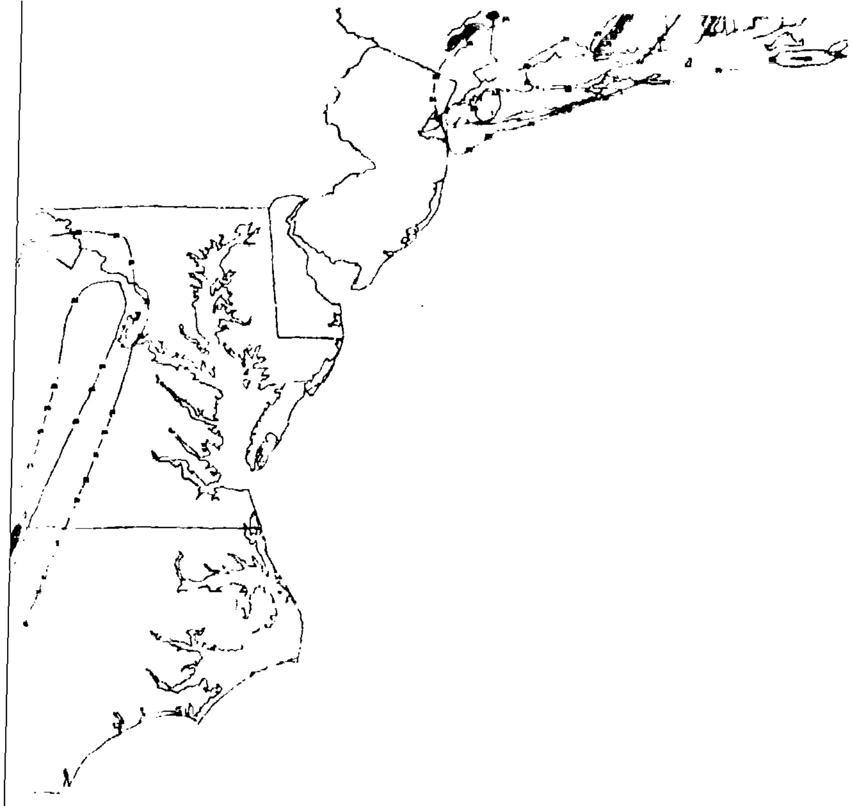


FAA STATIONS ONLY

AIRBORNE SHF SATCOM TRANSMITTER FREQUENCY 8150 MHz

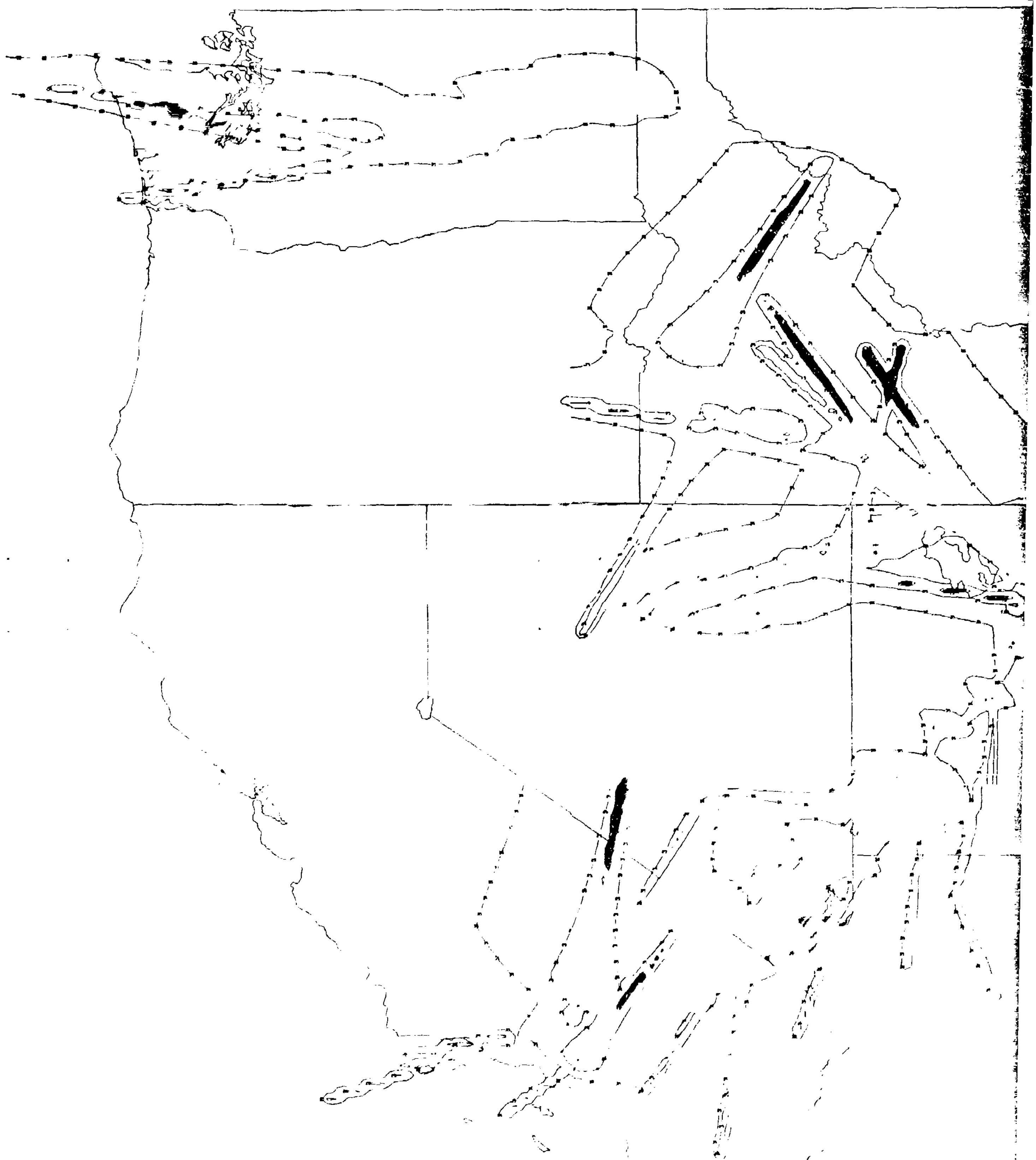
SATELLITE POSITION 13° WEST

(ASR-) SIGNAL LEVEL = -80 DBM BANDWIDTH = 15 MHz

(ASR-) SIGNAL LEVEL = -64 DBM

4

FIGURE 101: ATTIC PLOT OF CONTOURS FOR 13° WEST SATELLITE - 8150 MHz



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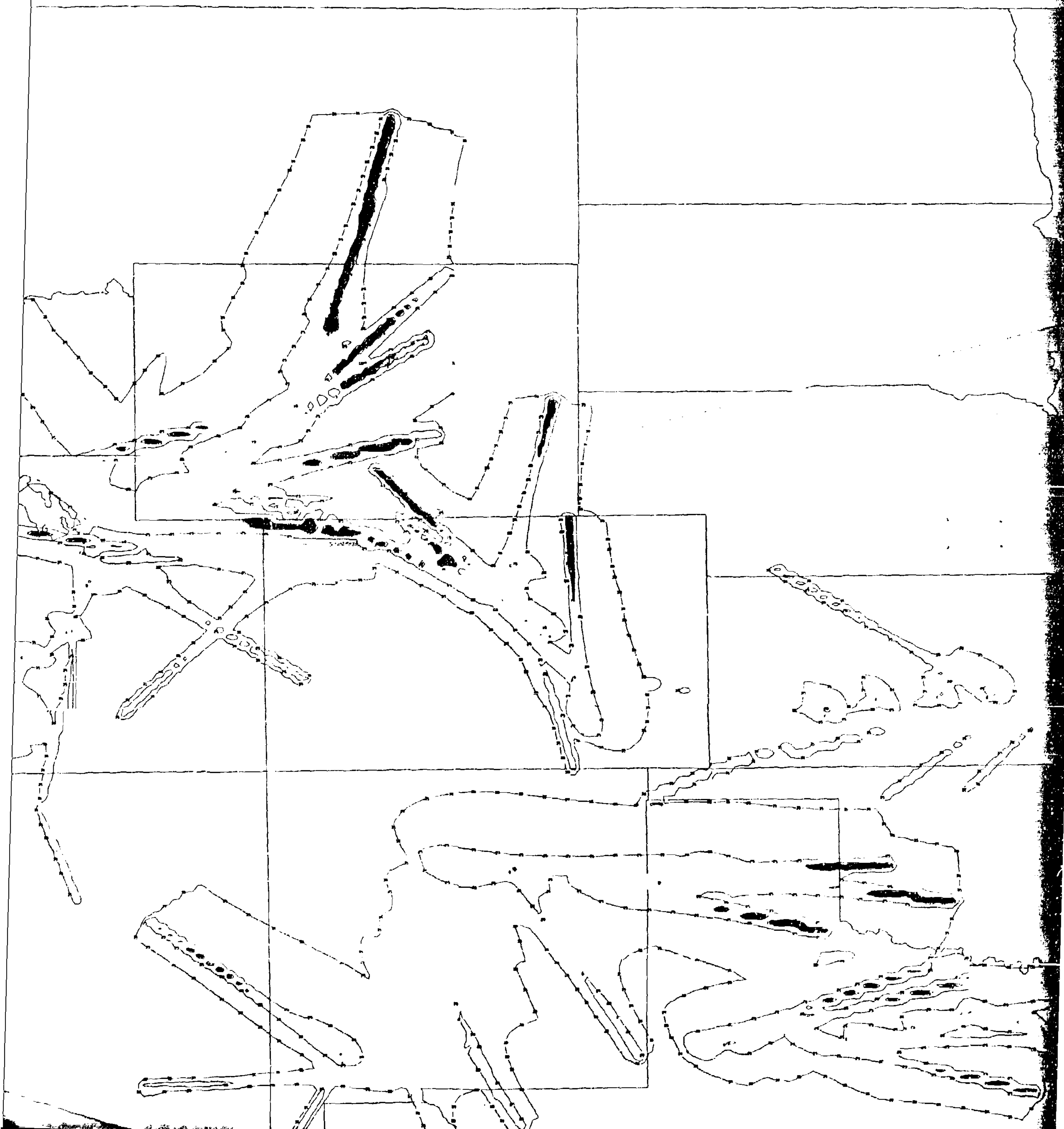

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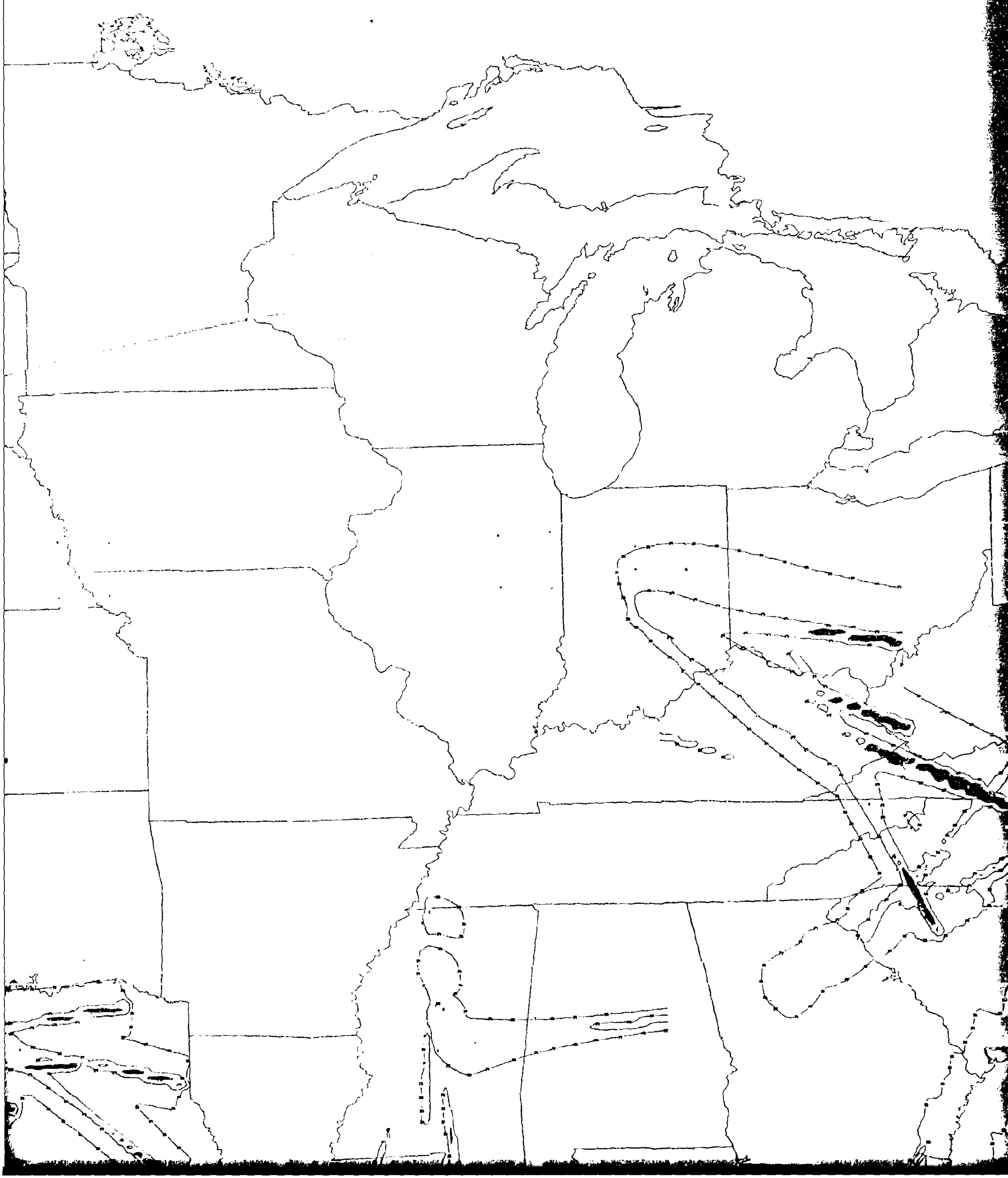

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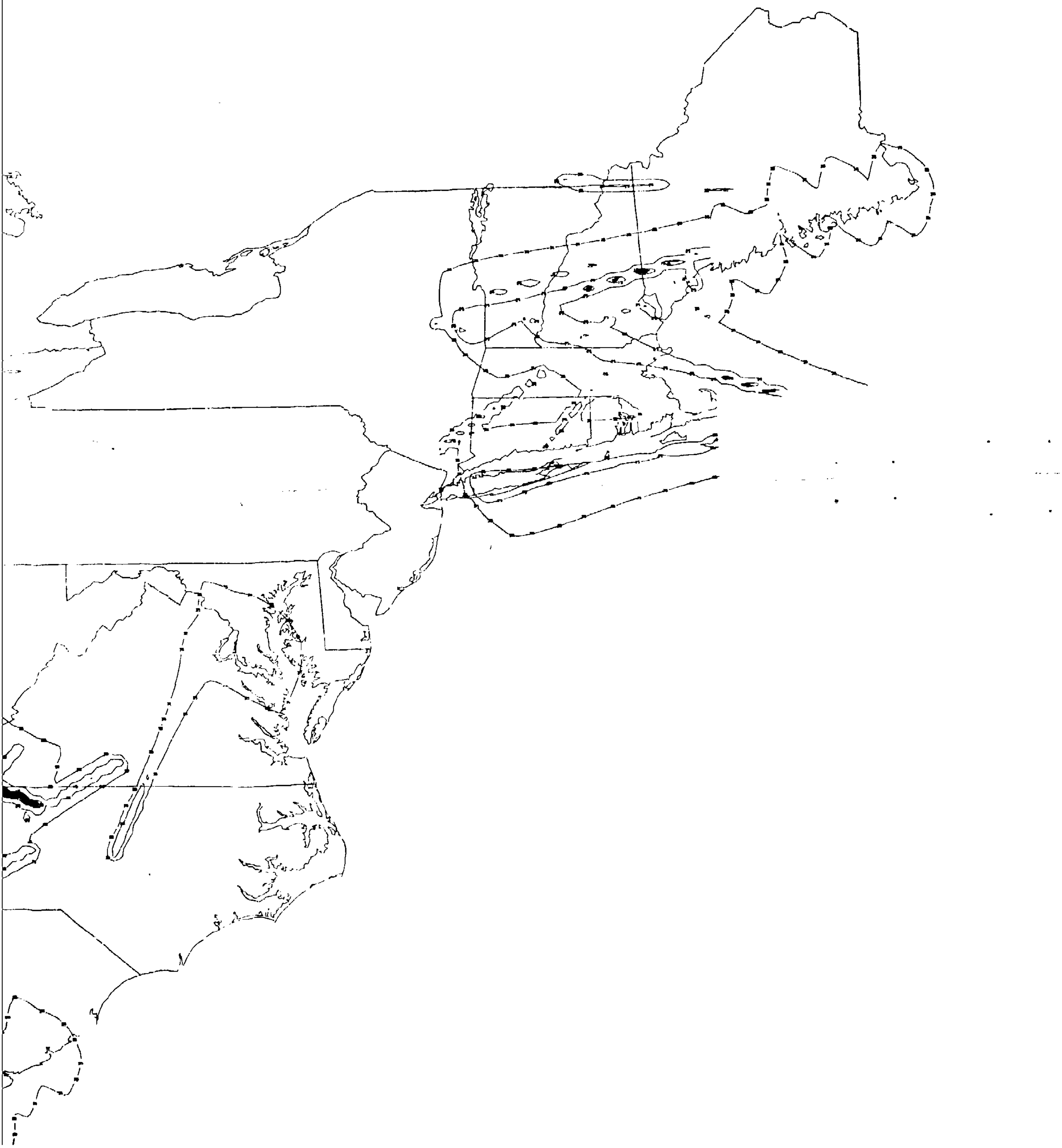

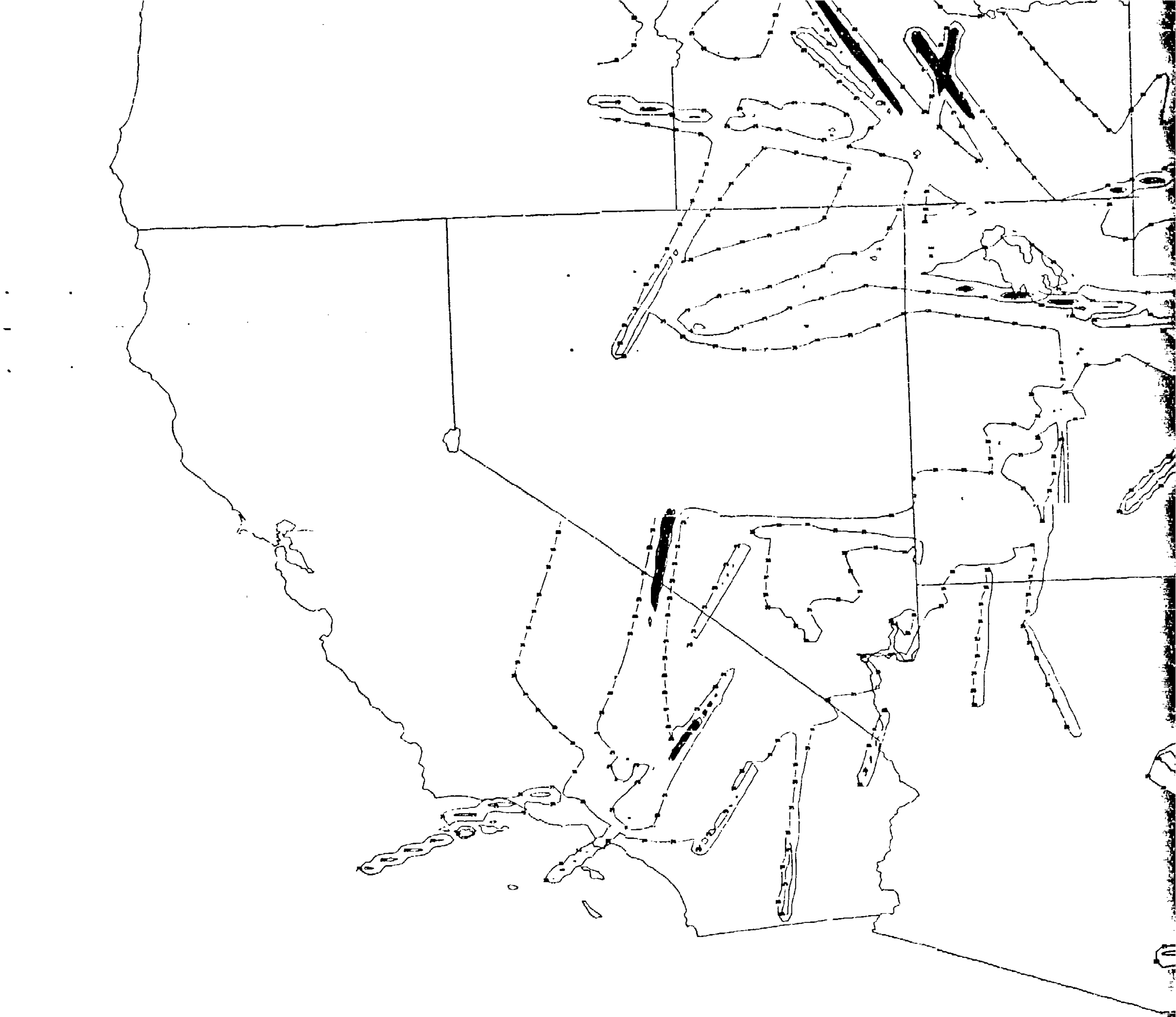

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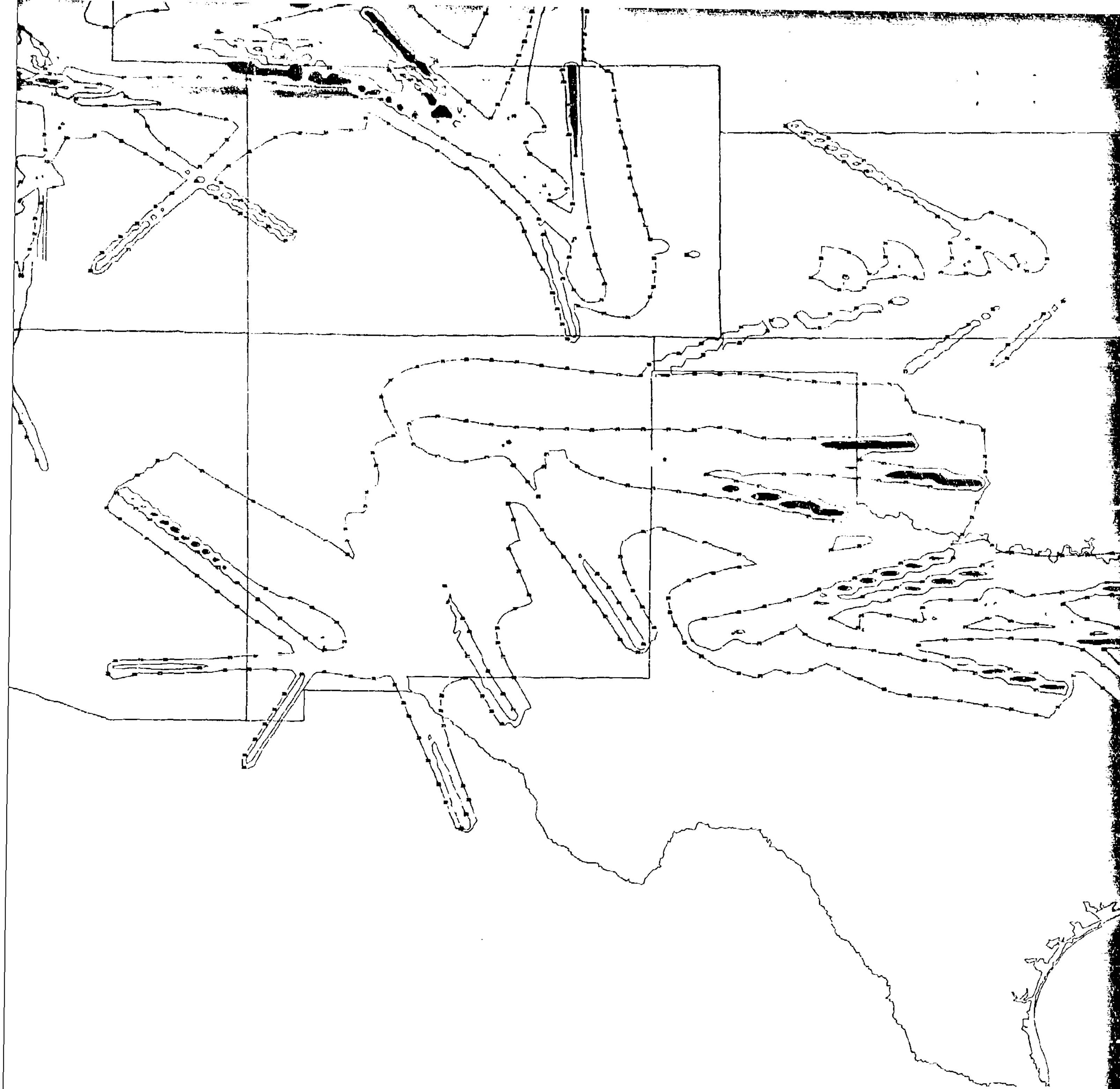

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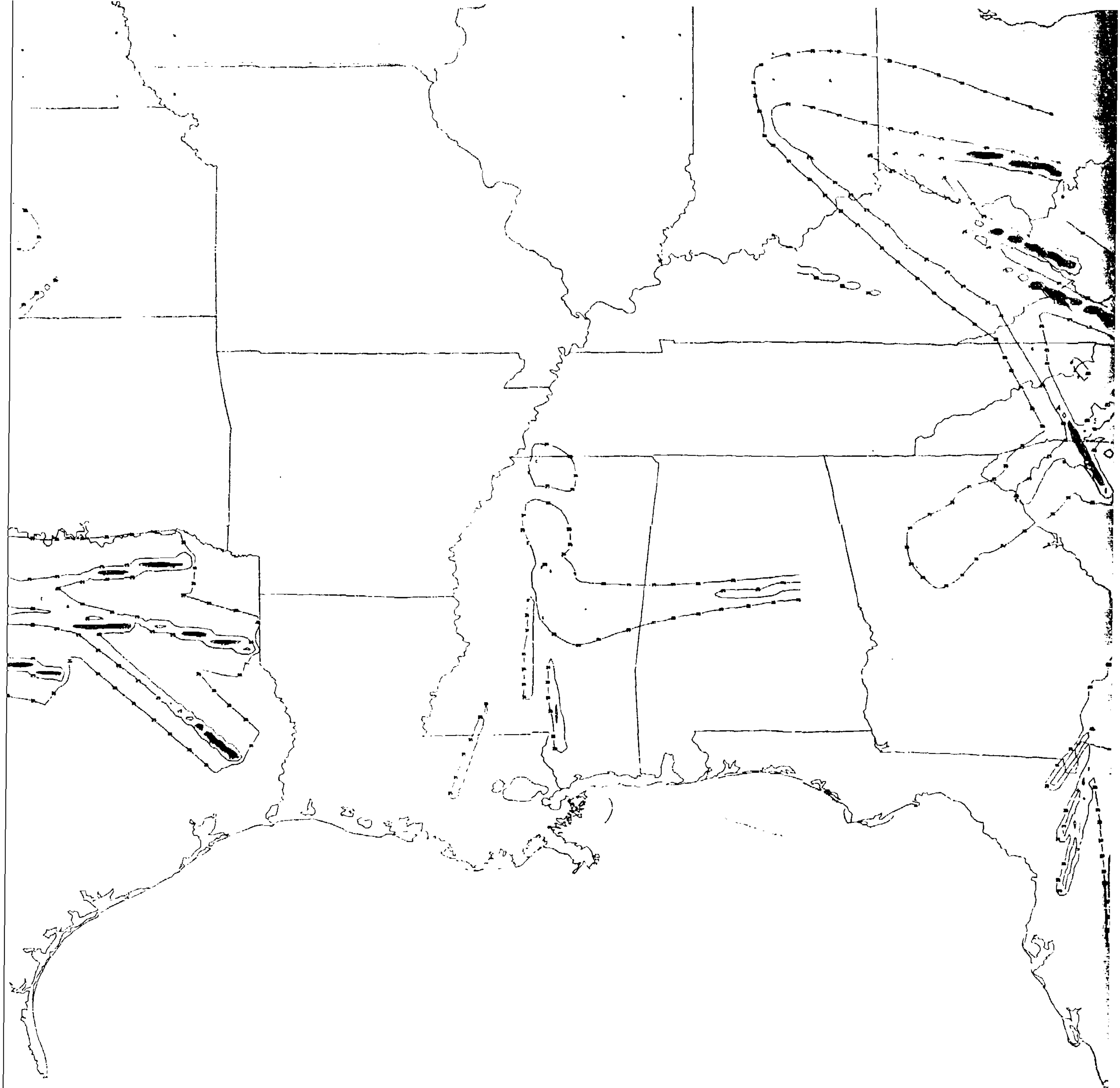

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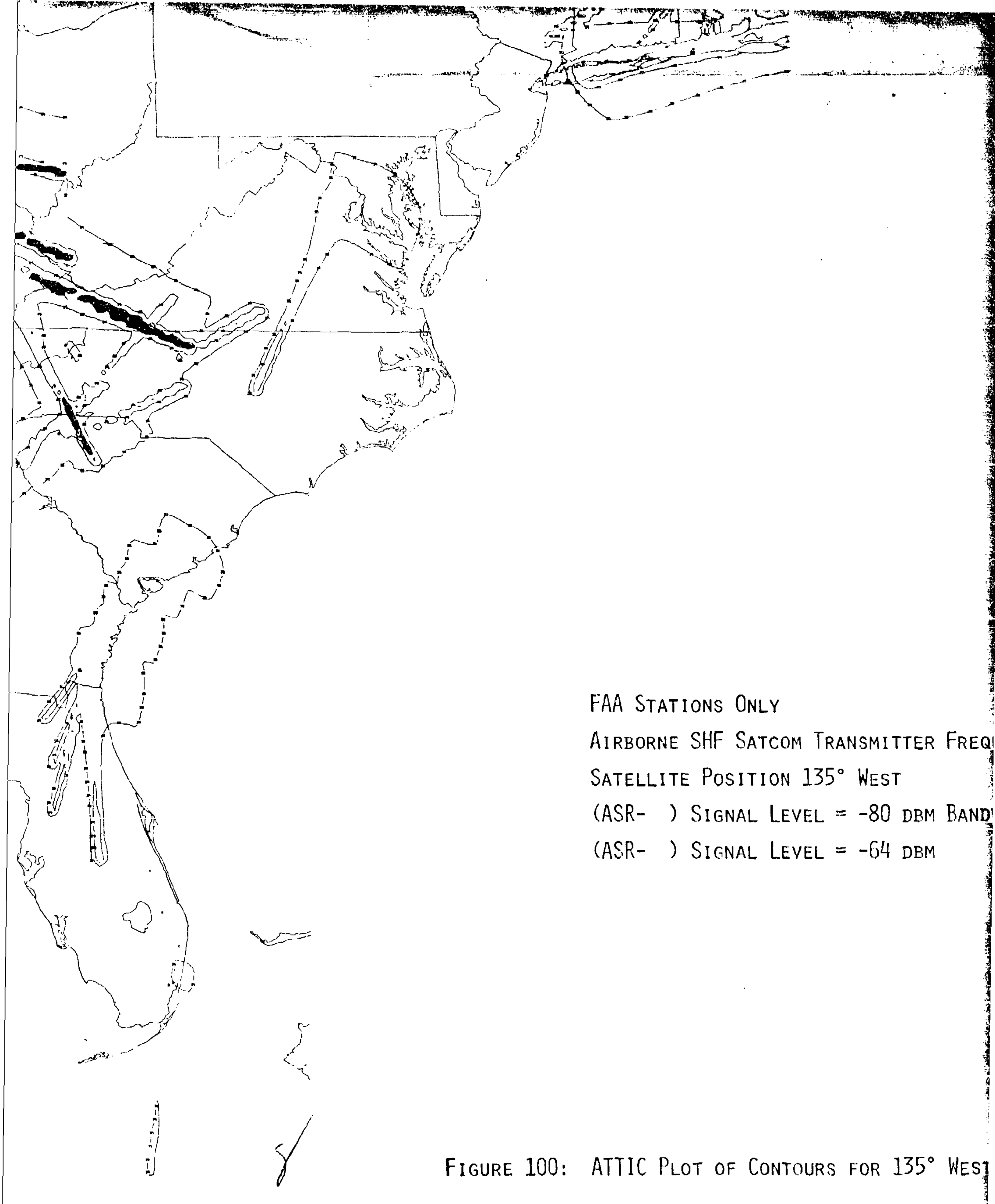


FAA Stations Only

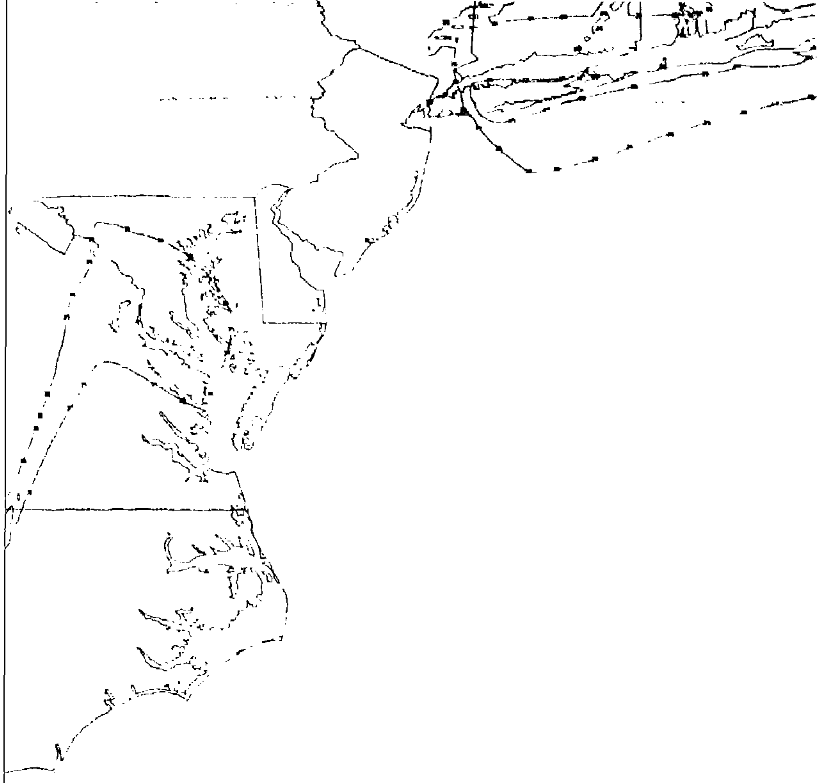
Airborne SHF Satcom Transmitter Freq

Satellite Position 135° West

(ASR-) Signal Level = -80 dBm Band

(ASR-) Signal Level = -64 dBm

Figure 100: ATTIC Plot of Contours for 135° West



FAA Stations Only

Airborne SHF Satcom Transmitter Frequency 8150 MHz

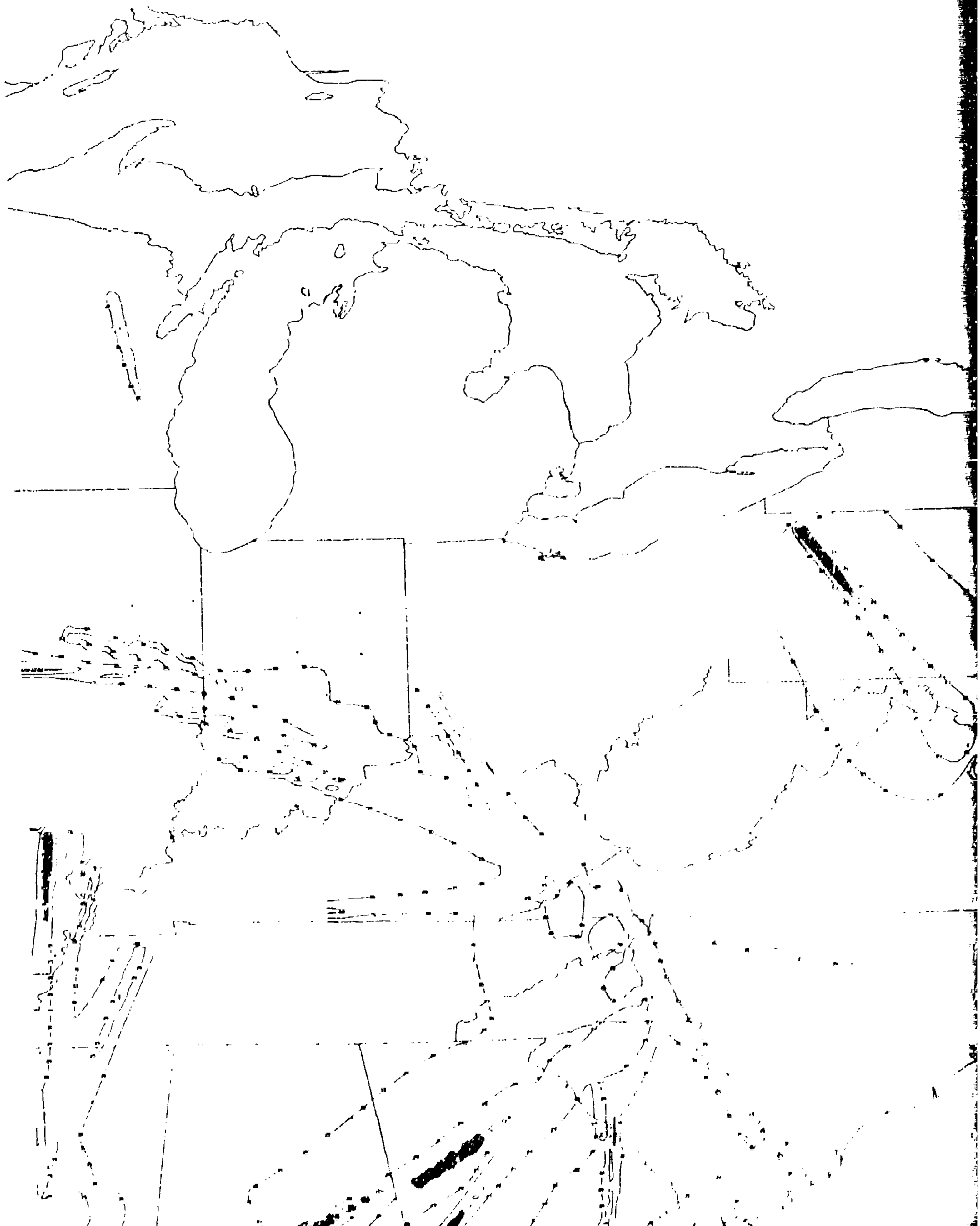
Satellite Position 135° West

(ASR-   ) Signal Level = -80 dBm Bandwidth = 15 MHz

(ASR-   ) Signal Level = -64 dBm

9

Figure 100: ATTIC Plot of Contours for 135° West Satellite - 8150 MHz



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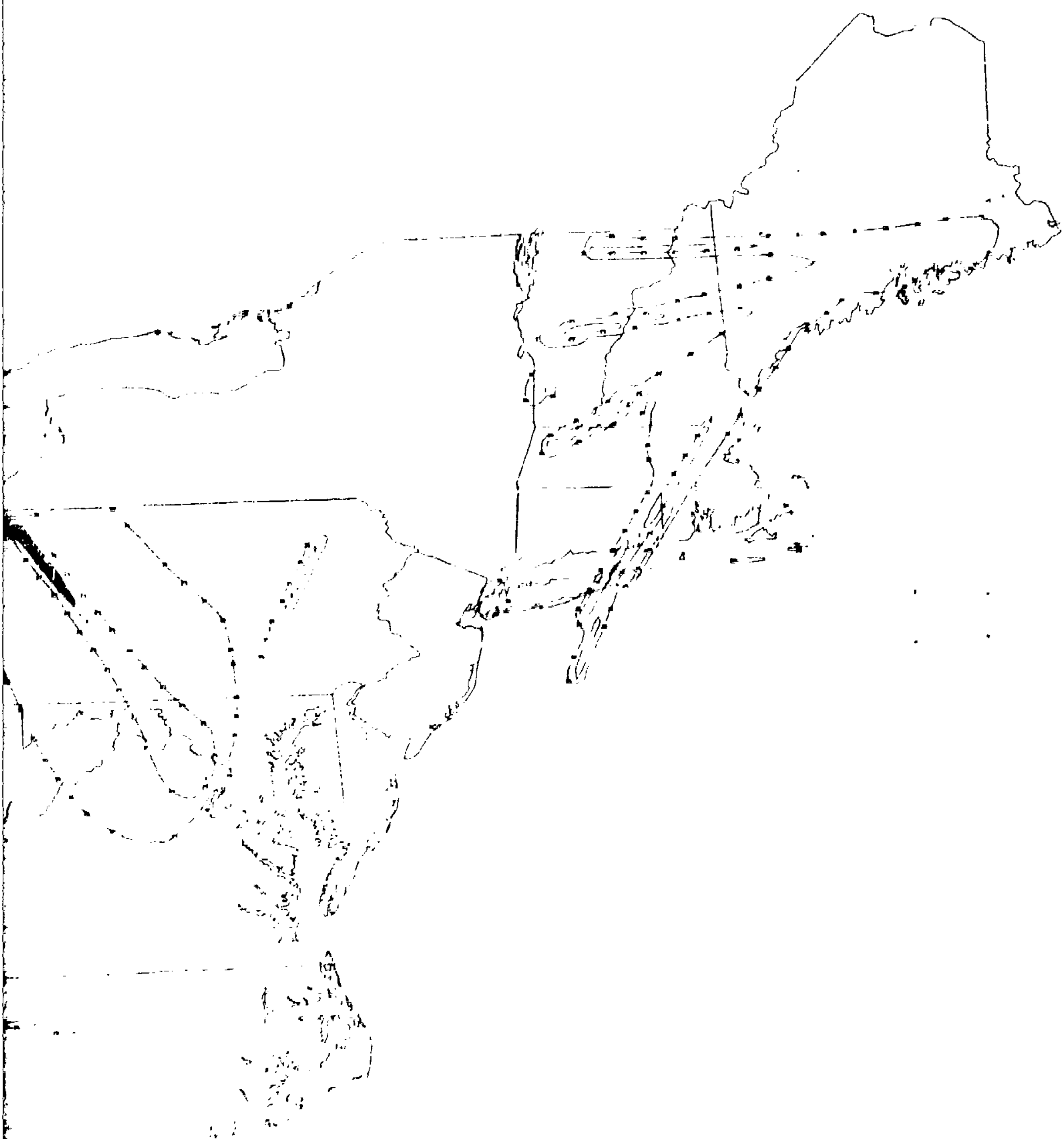

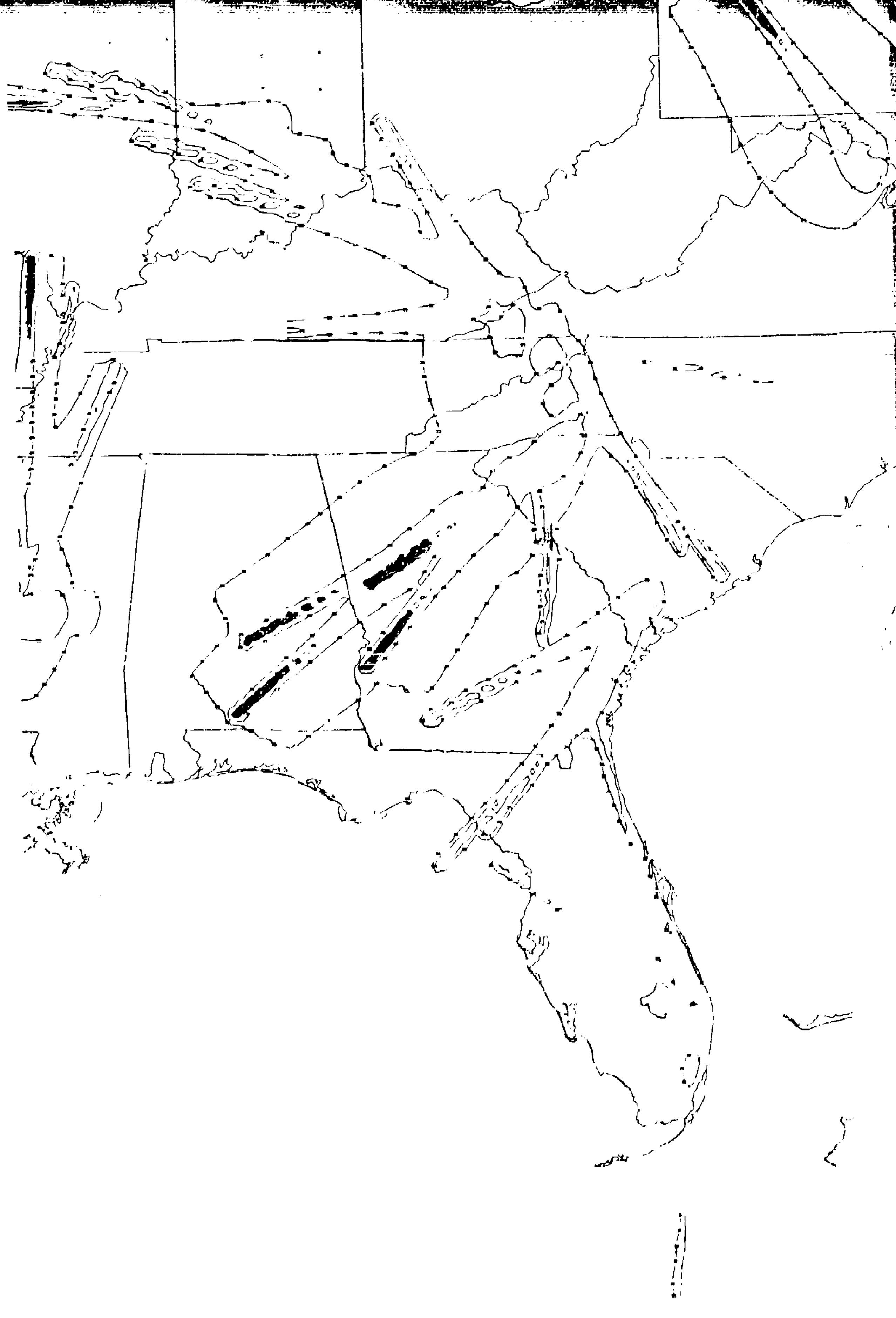

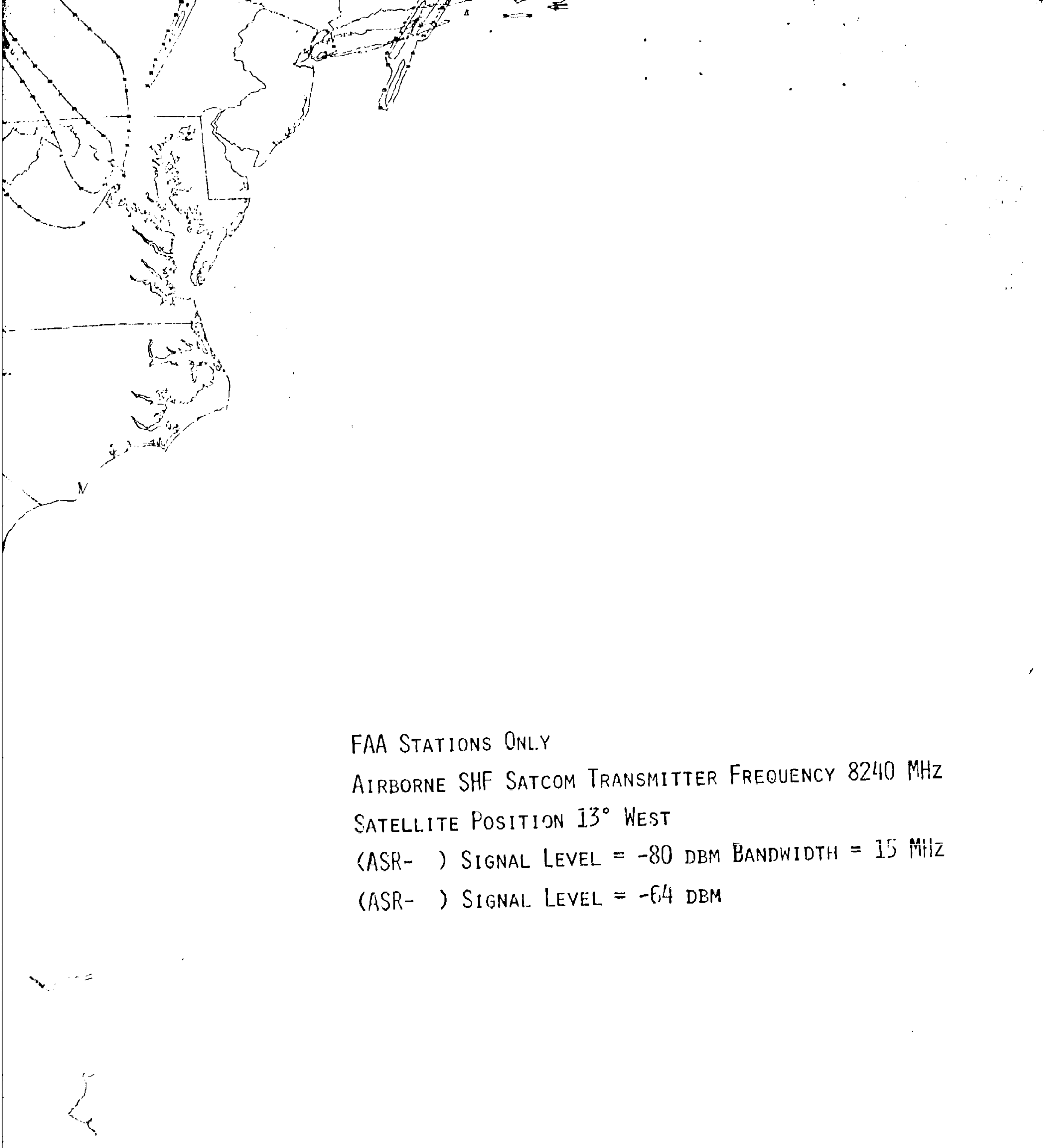

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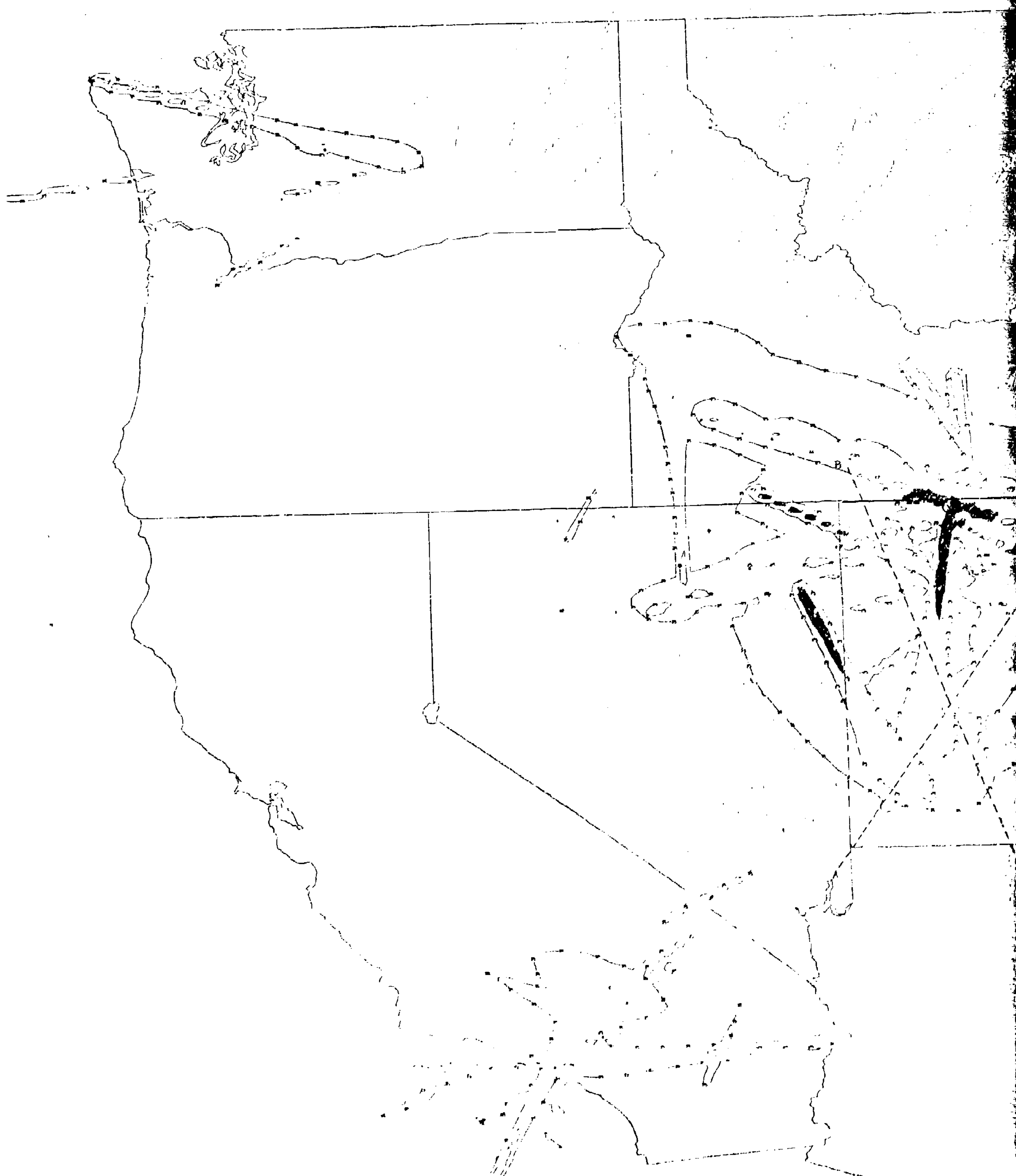
FIGURE 99: ATTIC PLOT OF CONTOURS FOR 13° WEST SATELLITE - 8240 MHz



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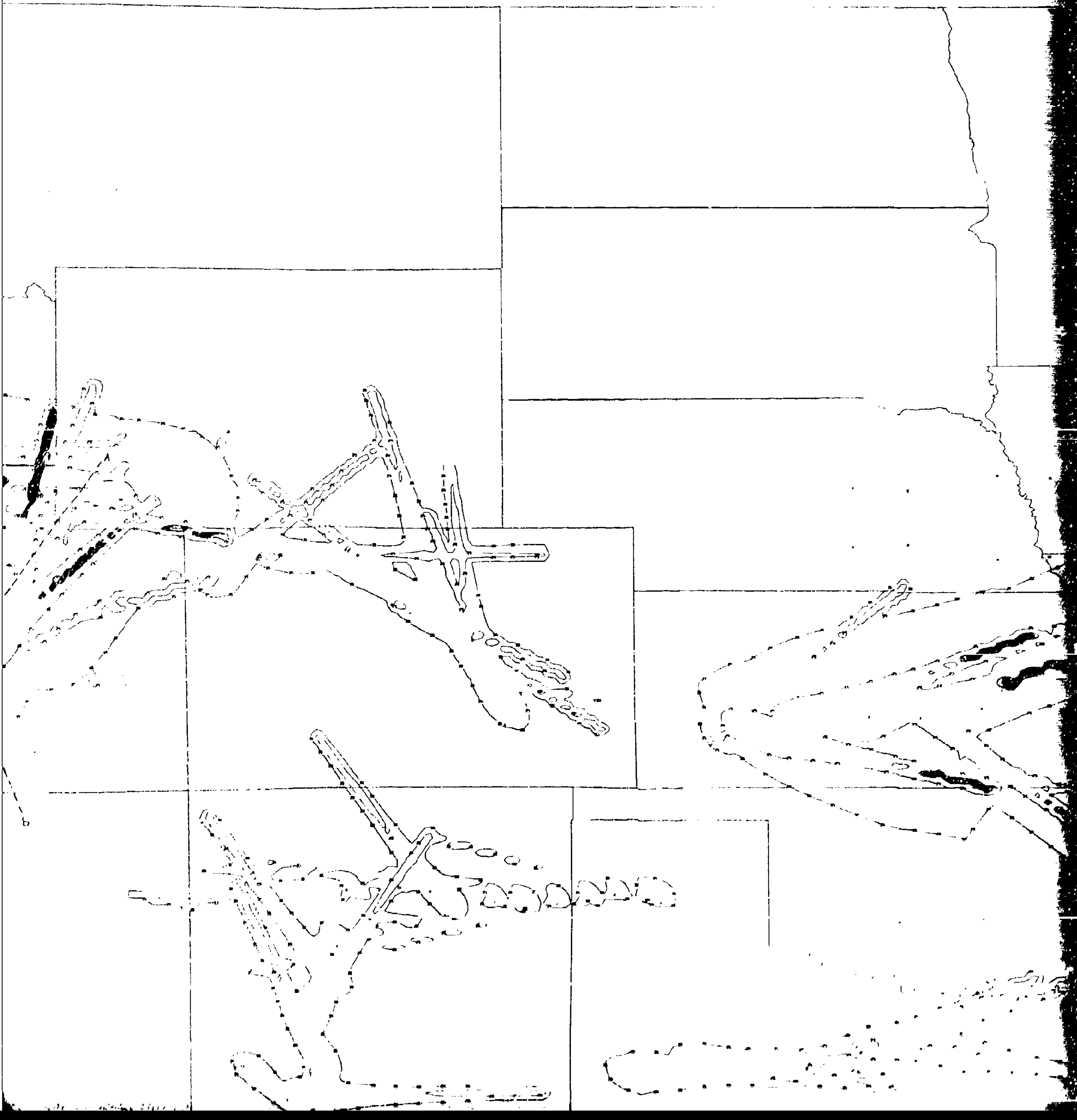

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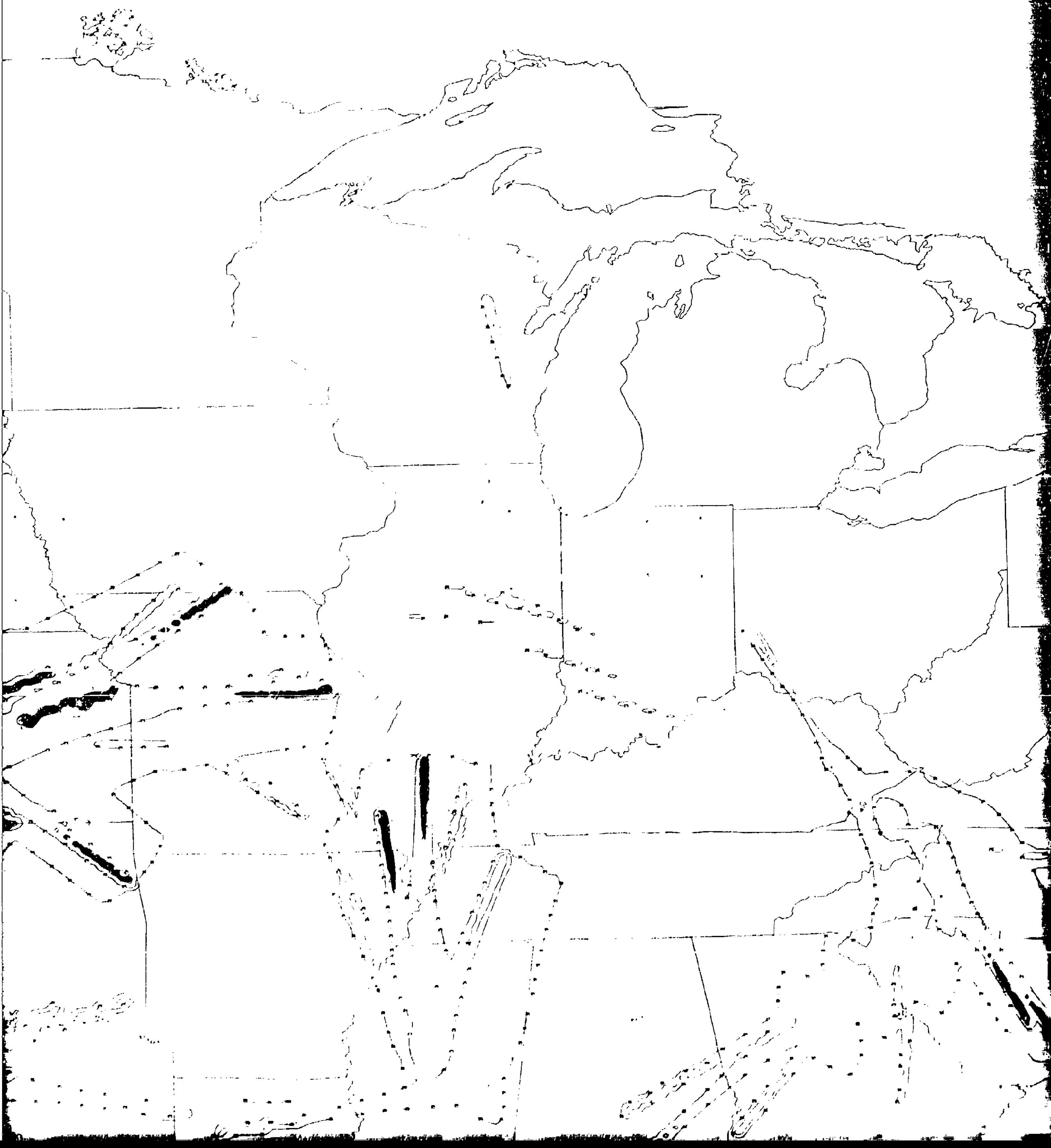

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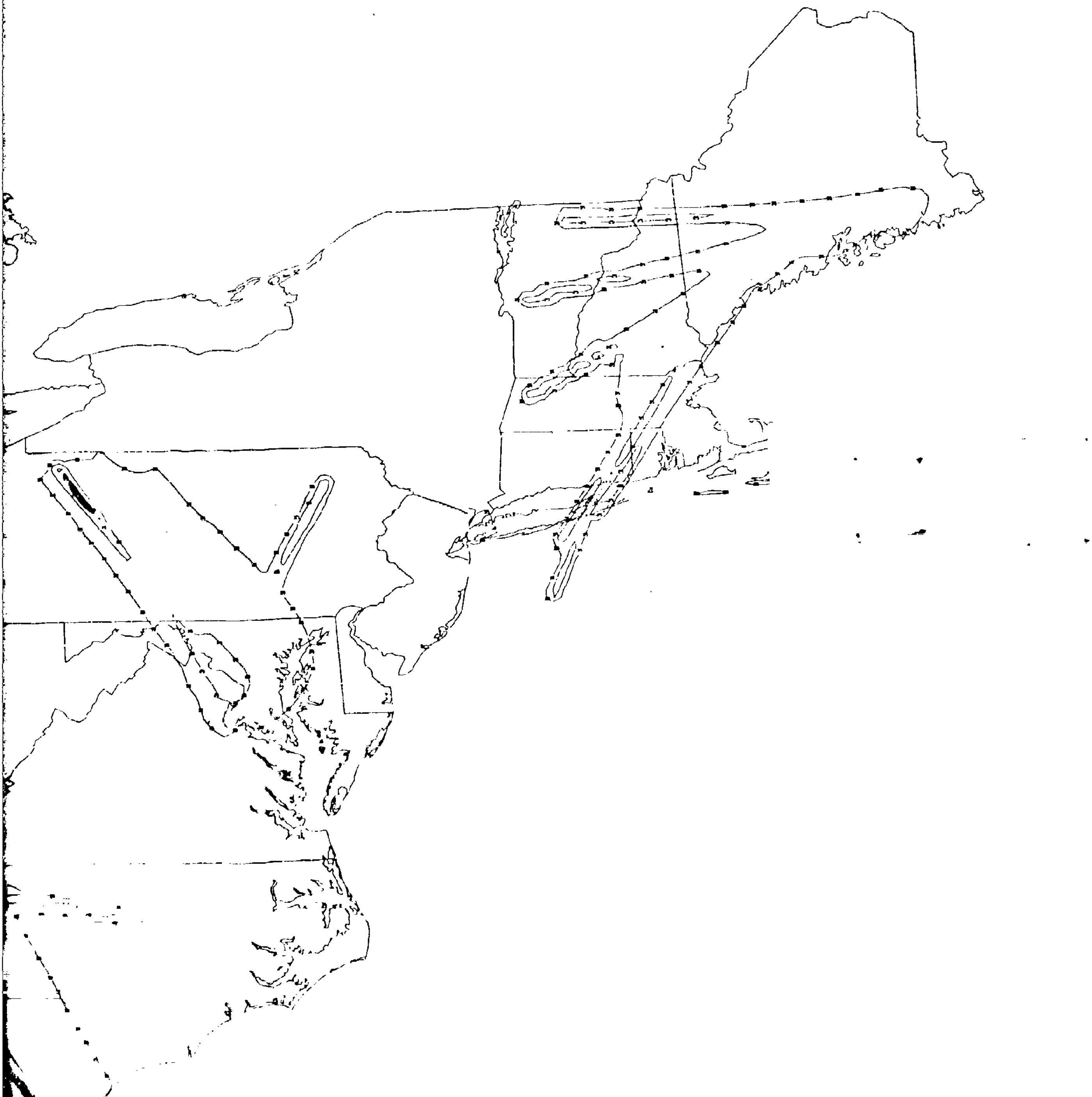

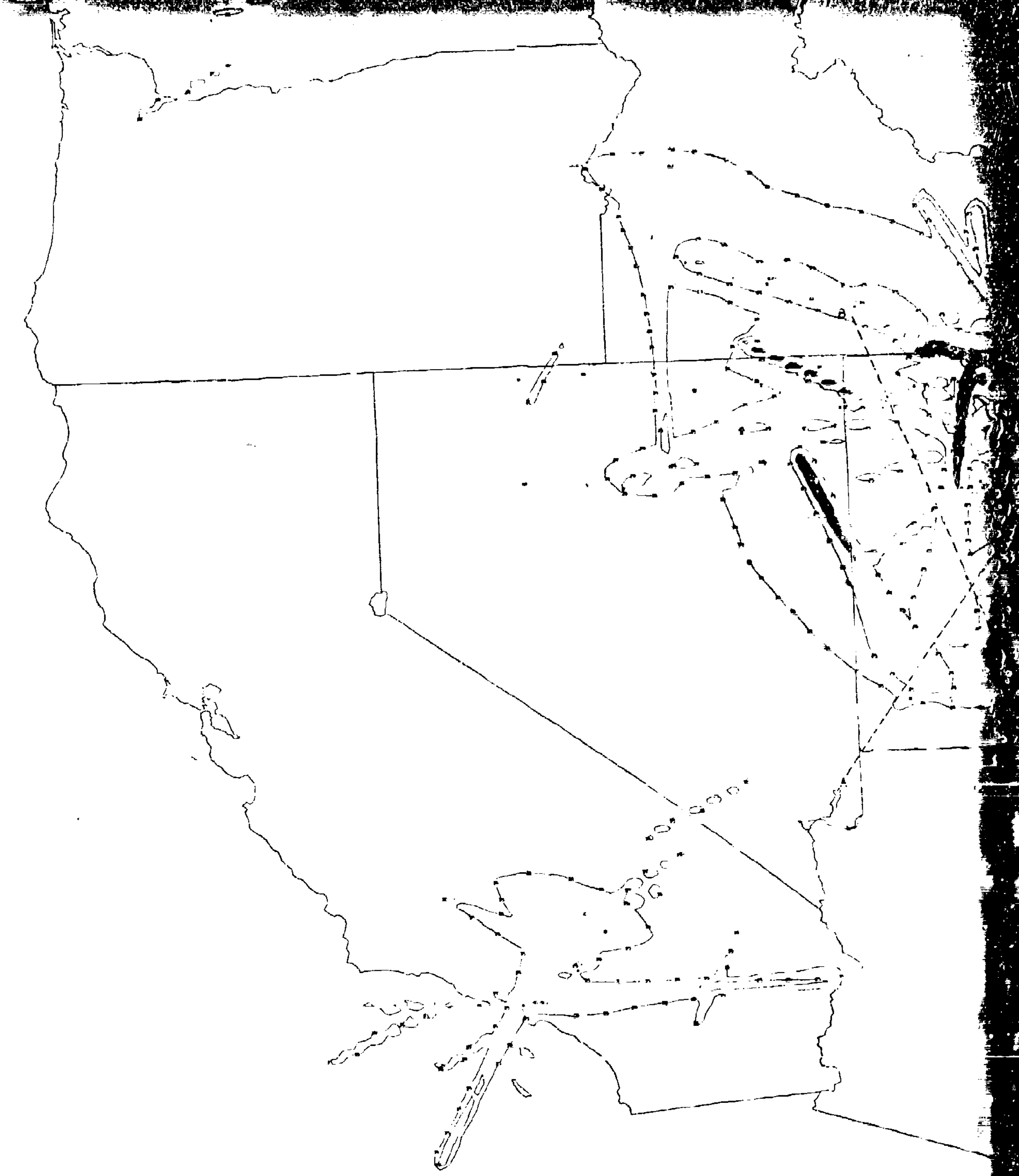

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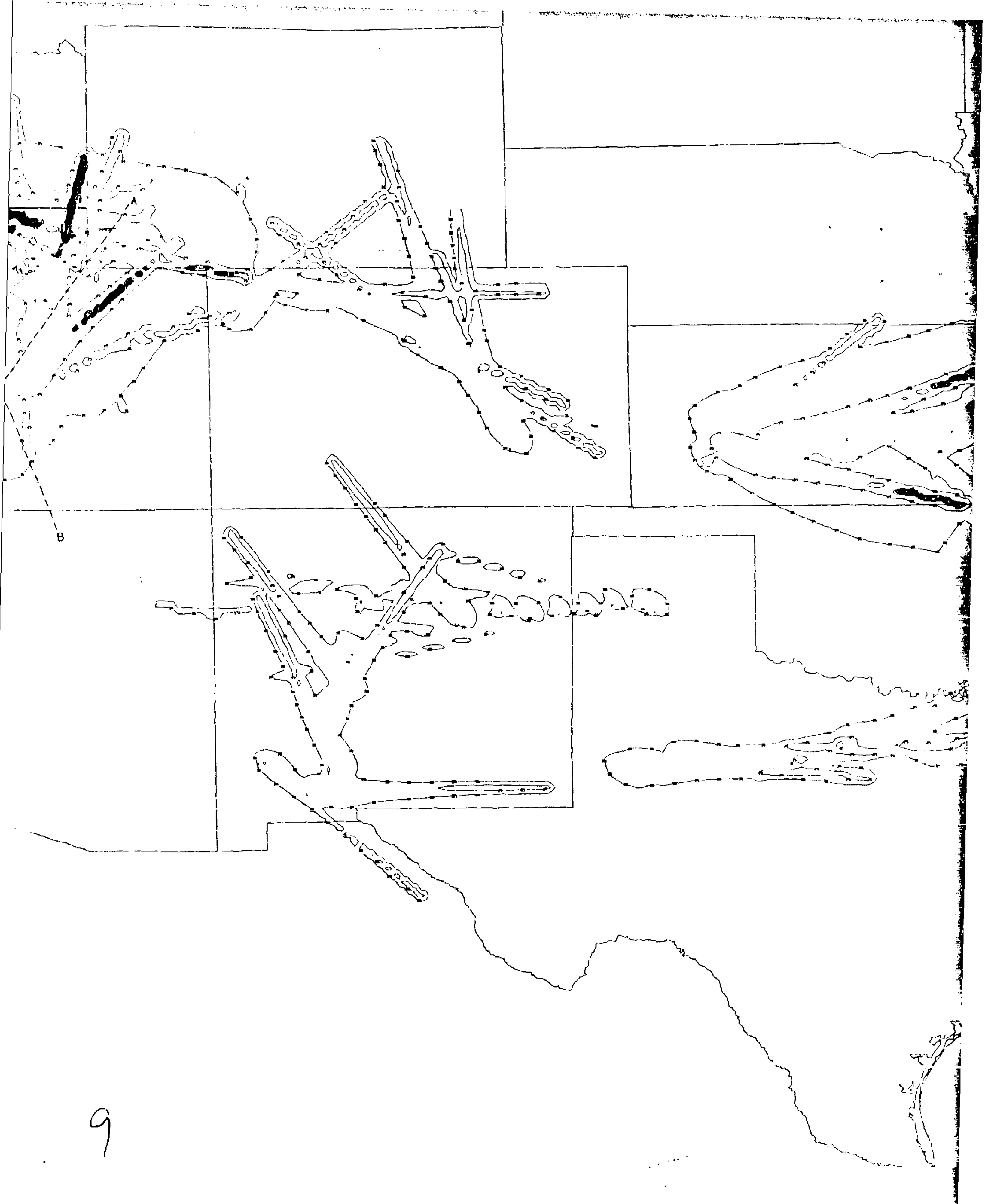

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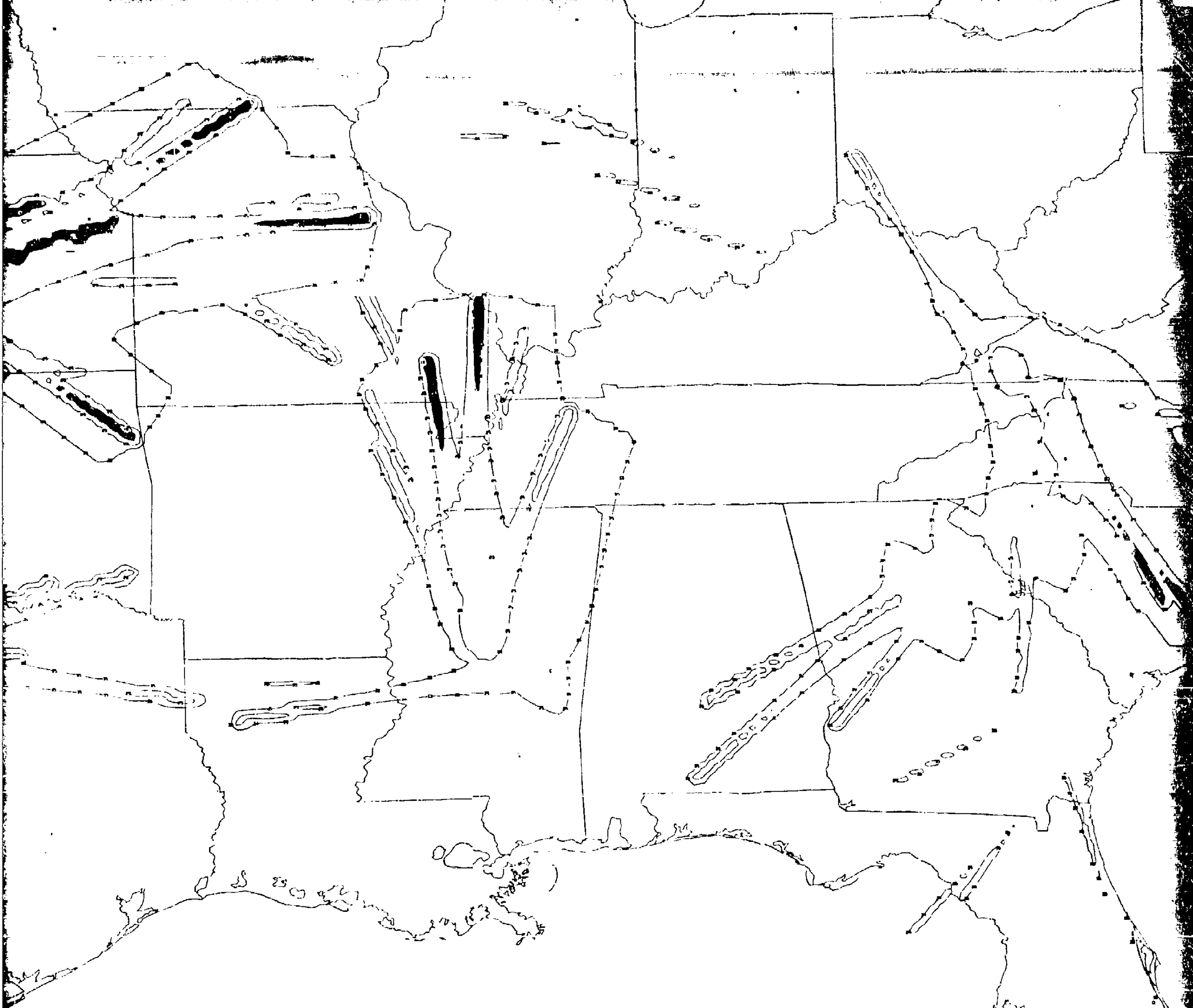

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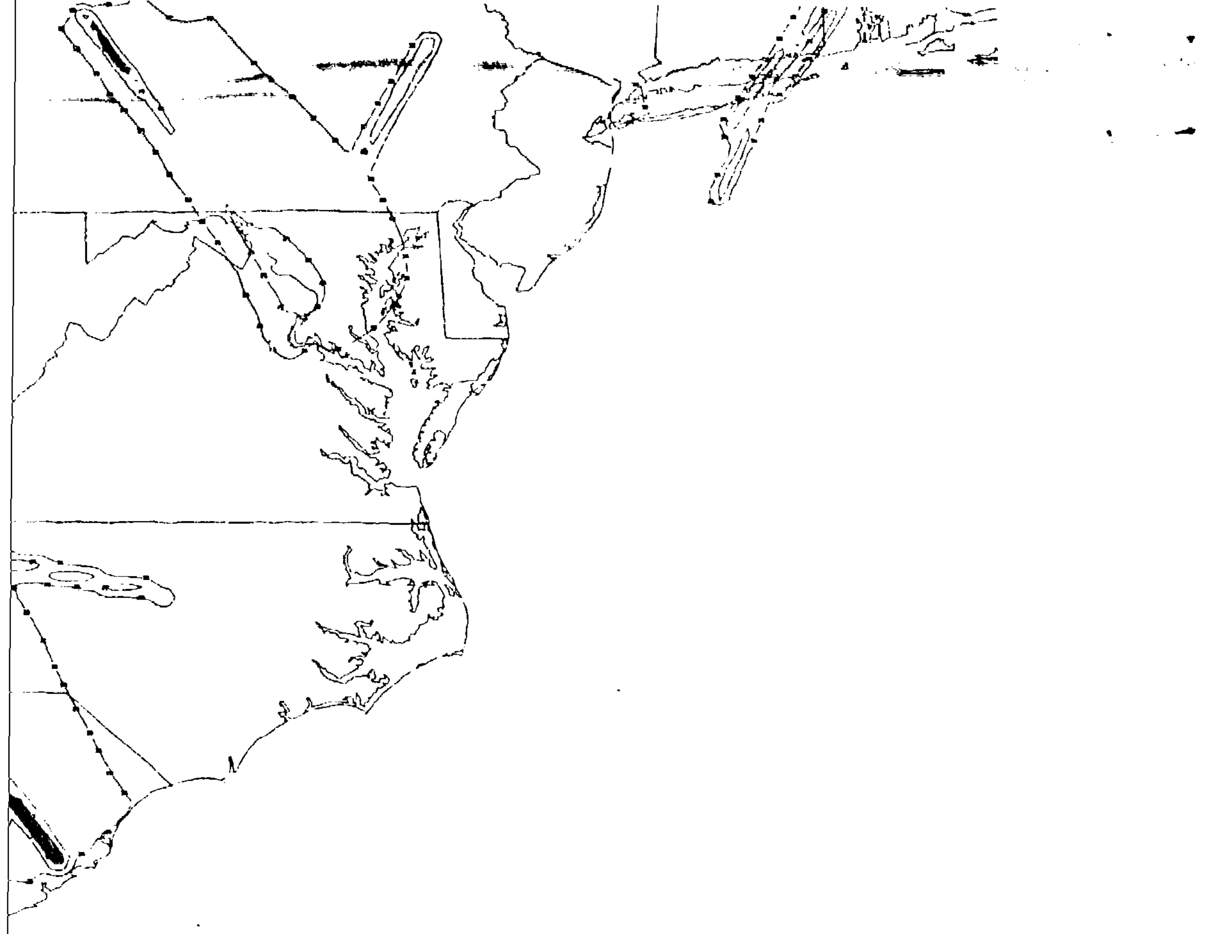

FAA STATIONS ONLY

AIRBORNE SHF SATCOM TRANSMITTER FREQUENCY 8240 MHz

SATELLITE POSITION 135° WEST

(ASR-) SIGNAL LEVEL - -80 DBM BANDWIDTH = 15 MHz

(ASR-) SIGNAL LEVEL = -64 DBM

FIGURE 98: ATTIC PLOT OF CONTOURS FOR 135° WEST SATELLITE -8240

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